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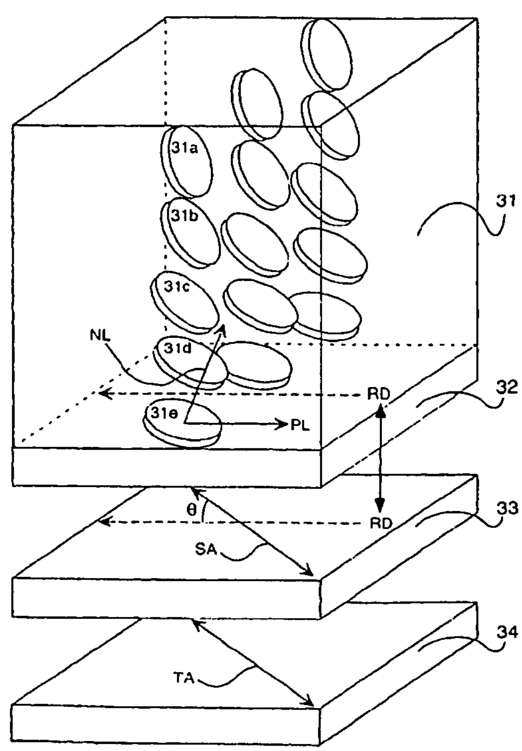
(54) Optical compensating sheet and liquid crystal display comprising the sheet

(57) A liquid crystal display comprises a liquid crystal cell of a bend alignment mode or a homogeneous alignment mode and two polarizing elements. Each of the elements is arranged on each side of the liquid crystal cell. At least one of the polarizing elements is an ellipsoidal polarizing plate. The ellipsoidal polarizing plate comprises a lamination of an optically anisotropic layer (31), a transparent substrate (33) and a polarizing membrane (34). The optically anisotropic layer contains discotic compounds (31a,...,31e). The transparent substrate is optically anisotropic. The polarizing membrane is arranged as an outermost layer of the liquid crystal display. The optically anisotropic layer and the transparent substrate are so arranged that an angle between a normal discotic direction and a slow axis (SA) in plane of the transparent substrate is essentially 45°. The normal discotic direction is an average of directions obtained by projecting normal lines (NL) of discotic planes of the discotic compounds on the plane of the substrate. The transparent substrate and the polarizing membrane are so arranged that the slow axis (SA) in plane of the transparent substrate is essentially parallel to or essentially perpendicular to the transmission axis (TA) of the polarizing membrane.

Fig. 3



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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a liquid crystal display of a bend alignment mode or a homogeneous alignment mode. The invention also relates to an ellipsoidal polarizing plate used in the liquid crystal display.

BACKGROUND OF THE INVENTION

[0002] A liquid crystal display (LCD) has advantages of thin shape, light weight and low consumption of electric power, compared with a cathode ray tube (CRT). The liquid crystal display comprises a liquid crystal cell and two polarizing elements arranged on both sides of the liquid crystal cell. The liquid crystal cell comprises a pair of substrates, rod-like liquid crystal compounds and an electrode layer. The rod-like liquid crystal compounds are provided between the substrates. The electrode layer has a function of applying a voltage to the rod-like liquid crystal compound. Each of the substrates has an orientation layer, which has a function of aligning the rod-like liquid crystal compound.

[0003] An optically compensatory sheet (a phase retarder) is usually provided between the liquid crystal cell and the polarizing elements to remove color from an image displayed on the liquid crystal cell. A lamination of the optically compensatory sheet and the polarizing element (polarizing membrane) functions as an ellipsoidal polarizing plate. A stretched birefringent film has usually been used as the optical compensatory sheet.

[0004] It has been proposed to use an optical compensatory sheet comprising an optically anisotropic layer containing discotic compounds on a transparent substrate in place of the stretched birefringent film. The optically anisotropic layer is formed by fixing aligned discotic compounds. The discotic compound usually has a large birefringence. Accordingly, an optical compensatory sheet obtained by using the discotic compound has a specific optical characteristic that cannot be obtained by the conventional stretched birefringent film. The optical compensatory sheet using the discotic compound is described in Japanese Patent Provisional Publication No. 6(1994)-214116, U.S. Patent Nos. 5,583,679, 5,646,703 and German Patent Publication No. 3,911,620A1.

[0005] U.S. Patent Nos. 4,583,825 and 5,410,422 disclose a liquid crystal display of a bend alignment mode having a liquid crystal cell in which rod-like liquid crystal compounds are aligned symmetrically. The alignment of an upper liquid crystal compound is essentially antiparallel to the alignment of a lower liquid crystal compound. The liquid crystal cell of the bend alignment mode has a self-optically compensatory function because of the symmetrical alignment. Therefore, the bend alignment mode is also referred to as an optically compensatory bend (OCB) mode. The liquid crystal display of the bend alignment mode has an advantage of a rapid response.

[0006] A liquid crystal cell of a homogeneous alignment mode has also been proposed. In the liquid crystal cell of the homogeneous alignment mode, rod-like liquid crystal compounds are essentially horizontally aligned while not applying voltage to the cell, and are essentially vertically aligned while applying voltage to the cell. The liquid crystal cell of the homogeneous alignment mode has recently been used in a liquid crystal display of an electrically controlled birefringence (ECB) type. The liquid crystal display of the ECB type is described in Japanese Patent Provisional Publication No. 5(1993)-203946.

[0007] The bend alignment mode and the homogeneous alignment mode are characterized in a wide viewing angle and a quick response compared with conventional liquid crystal modes (TN mode, STN mode). However, a further improvement is still necessary to be comparable with CRT.

[0008] It might be considered that an optical compensatory sheet is used to improve the liquid crystal display of the bend alignment mode or the homogeneous alignment mode in the same manner as in the conventional liquid crystal displays. However, the known optical compensatory sheet of a stretched birefringent film used in a conventional liquid crystal display is not effective in the liquid crystal display of the bend alignment mode or the homogeneous alignment mode. Particularly, the known stretched birefringent film shows a poor optical compensatory effect on the display of the bend alignment mode or the homogeneous alignment mode.

[0009] As is described above, an optical compensatory sheet comprising an optically anisotropic layer containing discotic compounds on a transparent substrate had been proposed in place of the stretched birefringent film. Japanese Patent Provisional Publication No. 9(1997)-197397 (U.S. Patent No. 5,805,253) and International Publication No. WO96/37804 (European Patent Publication No. 0783128A) disclose a liquid crystal display of a bend alignment mode, which has an optical compensatory sheet containing discotic compounds. The liquid crystal display of the bend alignment mode has been remarkably improved in the viewing angle by using the optical compensatory sheet containing discotic compounds.

SUMMERY OF THE INVENTION

[0010] The present inventor has studied a liquid crystal display of a bend alignment mode or a homogeneous align-

ment mode using an optical compensatory sheet containing discotic compounds. As a result, the present inventor has found a problem that a displayed image is colored with leaked light of a specific wavelength. The present inventor has further found that the problem is caused by a wavelength dependency of a transmittance of an ellipsoidal polarizing plate (a lamination of an optically compensatory sheet and a polarizing element). The present inventor has furthermore found that the wavelength dependency of the transmittance is caused by a problem on an arrangement of an optically anisotropic layer, a transparent substrate and a polarizing membrane in the known liquid crystal display.

[0011] The prior art references (Japanese Patent Provisional Publication No. 9(1997)-197397 and International Publication No. WO96/37804) does not clearly describe the arrangement of an optically anisotropic layer, a transparent substrate and a polarizing membrane (particularly the direction of the slow axis of the transparent substrate). However, the present inventor considers that an optically anisotropic layer and a transparent substrate have been so arranged that a normal discotic direction (an average of directions obtained by projecting normal lines of discotic planes of discotic compounds on plane of the transparent substrate) is essentially parallel to a slow axis in plane of the transparent substrate, since the above-mentioned arrangement can easily be constructed. The present inventor also considers that a transparent substrate and a polarizing membrane are so arranged that an angle between a slow axis in plane of the transparent substrate and a transmission axis in plane of the polarizing membrane is essentially 45°.

[0012] In preparation of an ellipsoidal polarizing plate, a rubbing treatment of discotic compounds has usually been conducted along a longitudinal direction of a rolled transparent substrate because the treatment is easily conducted. The longitudinal direction of a rolled transparent substrate usually is a stretched direction, which corresponds to a slow axis of the transparent substrate. The rubbing direction corresponds to a normal discotic direction, which is an average of directions obtained by projecting normal lines of discotic planes of discotic compounds on plane of the substrate. Further, the optically anisotropic layer and the polarizing membrane should be so arranged that an angle between the normal discotic direction and the transmission axis in plane of the polarizing membrane is essentially 45° to obtain the maximum optically compensatory effect on a liquid crystal cell of a bend alignment mode or a homogeneous alignment mode.

[0013] In the case that a transparent substrate is placed between two polarizing membranes which are so arranged that the transmission axes of the membranes are perpendicular to each other, the transmittance (T) is defined by the following formula (3).

$$(3) \qquad T = \sin^2(2\phi)\sin^2(\pi Re/\lambda)$$

in which ϕ is an angle between a slow axis in plane of the transparent substrate and a transmission axis in plane of the polarizing membrane (of the light incident side); λ is a wavelength of light; and Re is a retardation value in plane of the transparent substrate measured at the wavelength of λ.

[0014] According to prior art, the angle between a slow axis in plane of the transparent substrate and a transmission axis in plane of the polarizing membrane (ϕ) was 45°. Accordingly, the $\sin^2(2\phi)$ was the maximum value (1). Therefore, a wavelength dependency was caused in the transmittance (T) because of the wavelength dependency of the retardation value in plane of the transparent substrate (Re).

[0015] An object of the present invention is to further improve a liquid crystal display of a bend alignment mode or a homogeneous alignment mode without causing color contamination on a displayed image.

[0016] Another object of the invention is to provide an ellipsoidal polarizing plate suitable for a liquid crystal display of a bend alignment mode or a homogeneous alignment mode.

[0017] The present invention provides a liquid crystal display comprising a liquid crystal cell of a bend alignment mode and two polarizing elements, each of which is arranged on each side of the liquid crystal cell, at least one of said polarizing elements being an ellipsoidal polarizing plate comprising a lamination of an optically anisotropic layer, a transparent substrate and a polarizing membrane, said optically anisotropic layer containing discotic compounds, said transparent substrate being optically anisotropic, and said polarizing membrane being arranged as an outermost layer of the liquid crystal display,

wherein the optically anisotropic layer and the transparent substrate are so arranged that an angle between a normal discotic direction and a slow axis in plane of the transparent substrate is essentially 45°, said normal discotic direction being an average of directions obtained by projecting normal lines of discotic planes of the discotic compounds on plane of the substrate, and wherein the transparent substrate and the polarizing membrane are so arranged that a slow axis in plane of the transparent substrate is essentially parallel to or essentially perpendicular to a transmission axis in plane of the polarizing membrane.

[0018] The invention also provides a liquid crystal display comprising a liquid crystal cell of a homogeneous alignment mode and two polarizing elements, each of which is arranged on each side of the liquid crystal cell, at least one of said polarizing elements being an ellipsoidal polarizing plate comprising a lamination of an optically anisotropic layer, a transparent substrate and a polarizing membrane, said optically anisotropic layer containing discotic compounds, said

transparent substrate being optically anisotropic, and said polarizing membrane being arranged as an outermost layer of the liquid crystal display,

wherein the optically anisotropic layer and the transparent substrate are so arranged that an angle between a normal discotic direction and a slow axis in plane of the transparent substrate is essentially 45°, said normal discotic direction being an average of directions obtained by projecting normal lines of discotic planes of the discotic compounds on plane of the substrate, and wherein the transparent substrate and the polarizing membrane are so arranged that a slow axis in plane of the transparent substrate is essentially parallel to or essentially perpendicular to a transmission axis in plane of the polarizing membrane.

[0019] The invention further provides an ellipsoidal polarizing plate comprising a lamination of an optically anisotropic layer. a transparent substrate and a polarizing membrane, said optically anisotropic layer containing discotic compounds, said transparent substrate being optically anisotropic, and said polarizing membrane being arranged as an outermost layer,

wherein the optically anisotropic layer and the transparent substrate are so arranged that an angle between a normal discotic direction and a slow axis in plane of the transparent substrate is essentially 45°, said normal discotic direction being an average of directions obtained by projecting normal lines of discotic planes of the discotic compounds on plane of the substrate, and wherein the transparent substrate and the polarizing membrane are so arranged that a slow axis in plane of the transparent substrate is essentially parallel to or essentially perpendicular to a transmission axis in plane of the polarizing membrane.

[0020] In the present specification, the term "essentially 45°." the term "essentially parallel," the term "essentially perpendicular" or the like means that a margin for error based on the exactly angle is in the range of ±5°. The margin for error is preferably in the range of ±4°, more preferably in the range of ±3°, and most preferably in the range of ±2°.

[0021] In the specification, the term "slow axis," the term "fast axis," and the term "transmission axis" mean the direction showing the maximum refractive index, the direction showing the minimum refractive index and the direction showing the maximum transmittance respectively.

[0022] The present inventor has succeeded in improving a viewing angle of a liquid crystal display of a bend alignment mode or a homogeneous alignment mode without causing color contamination on a displayed image. The liquid crystal display is improved by changing the arrangement of the an optically anisotropic layer, a transparent substrate and a polarizing membrane.

[0023] The formula (3) is cited again.

$$(3) \qquad T = \sin^2(2\phi)\sin^2(\pi Re/\lambda)$$

in which ϕ is an angle between a slow axis in plane of the transparent substrate and a transmission axis in plane of the polarizing membrane (of the light incident side); λ is a wavelength of light; and Re is a retardation value in plane of the transparent substrate measured at the wavelength of λ.

[0024] According to the present invention, the angle between a slow axis in plane of the transparent substrate and a transmission axis in plane of the polarizing membrane (ϕ) is adjusted to 0° or 90°. Accordingly, the $\sin^2(2\phi)$ is the minimum value (0). Therefore, the wavelength dependency of the retardation value in plane of the transparent substrate (Re) does not affect on the transmittance (T).

[0025] On the other hand, the optically anisotropic layer and the polarizing membrane are so arranged that an angle between the normal discotic direction and the transmission axis in plane of the polarizing membrane is essentially 45° in the same manner as in prior art. Therefore, the maximum optically compensatory effect on a liquid crystal cell of a bend alignment mode or a homogeneous alignment mode can be obtained by the present invention in the same manner as in prior art.

[0026] For the reasons mentioned above, the liquid crystal display of a bend alignment mode or a homogeneous alignment mode is further improved in the viewing angle without causing color contamination on a displayed image.

[0027] In preparation of an ellipsoidal polarizing plate, the prior art is advantageous to the present invention. However, the advantage is not serious. The rubbing treatment of discotic compounds is conducted along a direction of 45° to the longitudinal direction of a rolled transparent substrate according to the present invention, while the rubbing treatment has been conducted along the longitudinal direction according to the prior art. Therefore, the liquid crystal display and the ellipsoidal polarizing plate of the present invention can be prepared by slightly modifying a conventional manufacturing apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] Fig. 1 is a sectional view schematically illustrating alignment of liquid crystal molecules in a liquid crystal cell of a bend alignment mode.

[0029] Fig. 2 is a sectional view schematically illustrating alignment of liquid crystal molecules in a liquid crystal cell of a homogeneous alignment mode.
[0030] Fig. 3 schematically illustrates an ellipsoidal polarizing plate according to the present invention.
[0031] Fig. 4 schematically illustrates a liquid crystal display of a bend alignment mode according to the present invention.
[0032] Fig. 5 schematically illustrates a relation of optical compensation in a liquid crystal display of a bend alignment mode.
[0033] Fig. 6 schematically illustrates a liquid crystal display of a homogeneous alignment mode according to the present invention.
[0034] Fig. 7 schematically illustrates a relation of optical compensation in a liquid crystal display of a homogeneous alignment mode.
[0035] Fig. 8 schematically illustrates various embodiments of an ellipsoidal polarizing plate.
[0036] Fig. 9 schematically illustrates other various embodiments of an ellipsoidal polarizing plate.

DETAILED DESCRIPTION OF THE INVENTION

[0037] A liquid crystal display and an ellipsoidal polarizing plate are described by referring to the drawings.
[0038] Fig. 1 is a sectional view schematically illustrating alignment of liquid crystal molecules in a liquid crystal cell of a bend alignment mode.
[0039] As is shown in Fig. 1, a bend alignment liquid crystal cell comprises an upper substrate (14a), a lower substrate (14b) and liquid crystal compounds (11) sealed between the substrates. The liquid crystal compounds (11) used in a bend alignment liquid crystal cell generally has a positive dielectric constant anisotropy. Each of the upper substrate (14a) and lower substrate (14b) has an orientation layer (12a, 12b) and an electrode (13a, 13b). The orientation layer has a function of aligning the rod-like liquid crystal molecules (11a to 11j). RD in Fig. 1 means the rubbing direction of the orientation layer. The electrode has a function of applying voltage to the rod-like liquid crystal molecules (11a to 11j).
[0040] As is shown in (off) of Fig. 1, the alignment of the liquid crystal molecules (11a to 11e) near the upper substrate (14a) is substantially antiparallel (symmetrical) to the alignment of the molecules (11f to 11j) near the lower substrate (14b) when the applied voltage is low. The liquid crystal molecules (11a, 11b, 11i, 11j) neighboring the substrates (14a, 14b) are essentially horizontally aligned, while the liquid crystal molecules (11d to 11g) centered in the liquid crystal cell are essentially vertically aligned.
[0041] As is shown in (on) of Fig. 1, the liquid crystal molecules (11a, 11j) neighboring the substrates (14a, 14b) are still essentially horizontally aligned when the applied voltage is high. The liquid crystal molecules (11e, 11f) centered in the liquid crystal cell are still essentially vertically aligned. The alignment of the other liquid crystal molecules (11b, 11c, 11d, 11g, 11h, 11i) is changed when the applied voltage is increased. The molecules are rather vertically aligned compared with the alignment of the off state. The alignment of the liquid crystal molecules (11a to 11e) near the upper substrate (14a) is still substantially antiparallel (symmetrical) to the alignment of the molecules (11f to 11j) near the lower substrate (14b) even if the applied voltage is high.
[0042] Fig. 2 is a sectional view schematically illustrating alignment of liquid crystal molecules in a liquid crystal cell of a homogeneous alignment mode.
[0043] As is shown in Fig. 2, a homogeneous alignment liquid crystal cell comprises an upper substrate (24a), a lower substrate (24b) and liquid crystal compounds (21) sealed between the substrates. The liquid crystal compounds (21) used in a homogeneous alignment liquid crystal cell generally has a positive dielectric constant anisotropy. Each of the upper substrate (24a) and lower substrate (24b) has an orientation layer (22a, 22b) and an electrode (23a, 23b). The orientation layer has a function of aligning the rod-like liquid crystal molecules (21a to 21j). RD in Fig. 2 means the rubbing direction of the orientation layer. The electrode has a function of applying voltage to the rod-like liquid crystal molecules (21a to 21j).
[0044] As is shown in (off) of Fig. 2, the liquid crystal molecules (21a to 21j) are essentially horizontally aligned when the applied voltage is low. However, the aligned compounds are slightly slanted (pretilted) to a direction. The slanted compounds can be aligned to the pretilted direction when voltage is applied to the liquid crystal cell.
[0045] As is shown in (on) of Fig. 2, the liquid crystal molecules (21a to 21j) are rather vertically aligned when the applied voltage is high. However, the liquid crystal molecules (21a, 21j) neighboring the substrates (24a, 24b) are still essentially horizontally aligned when the applied voltage is high. The liquid crystal molecules (21d to 21g) centered in the liquid crystal cell are essentially vertically aligned.
[0046] Fig. 3 schematically illustrates an ellipsoidal polarizing plate according to the present invention.
[0047] As is shown in Fig. 3, an ellipsoidal polarizing plate comprises a lamination of an optically anisotropic layer (31) containing discotic compounds (31a to 31e), an optically anisotropic transparent substrate (33) and a polarizing membrane (34). The ellipsoidal polarizing plate shown in Fig. 3 further comprises an orientation layer (32) between the optically anisotropic layer (31) and the transparent substrate (33).

[0048] The discotic compounds (31a to 31e) contained in the optically anisotropic layer (31) are planer molecules. Each of the molecules has only one plane, namely discotic plane. The discotic planes are inclined to planes parallel to the surface of the transparent substrate (33). The angle between the discotic planes and the paralleled planes are inclined. As the distance between the molecule and the orientation layer (32) increases along a normal line of the transparent substrate (33), the inclined angles increase. The average inclined angle is preferably in the range of 15 to 50°. An ellipsoidal polarizing plate has a function of improving the viewing angle. The function can be further improved where the inclined angles are changed as is shown in Fig. 3. The ellipsoidal polarizing plate shown in Fig. 3 has another function of preventing an image from reversion, gray-scale inversion and color contamination of a displayed image.

[0049] The average of directions (PL) obtained by projecting normal lines (NL) of discotic planes of the discotic compounds (31a to 31e) on plane of the substrate (33) is antiparallel to the rubbing direction (RD) of the orientation layer (32). According to the present invention, an angle between a normal discotic direction (the average of PL directions) and a slow axis in plane of the transparent substrate is essentially adjusted to 45°. In preparation of the ellipsoidal polarizing plate, an angle (θ) between the rubbing direction (RD) of the orientation layer (32) and the slow axis (SA) in plane of the transparent substrate (33) is essentially adjusted to 45°.

[0050] Further, the transparent substrate (33) and the polarizing membrane (34) are so arranged that a slow axis (SA) in plane of the transparent substrate is essentially parallel to or essentially perpendicular to a transmission axis (TA) in plane of the polarizing membrane. In the ellipsoidal polarizing plate shown in Fig. 3, the slow axis (SA) in plane of the transparent substrate (33) is essentially parallel to the transmission axis (TA) in plane of the polarizing membrane (34). The slow axis (SA) in plane of the transparent substrate (33) generally corresponds to the stretching direction of the transparent substrate (33). The transmission axis (TA) in plane of the polarizing membrane (34) is generally perpendicular to the stretching direction of the polarizing membrane (34).

[0051] Fig. 4 schematically illustrates a liquid crystal display of a bend alignment mode according to the present invention.

[0052] The liquid crystal display shown in Fig. 4 comprises a liquid crystal cell of a bend alignment mode (10), two polarizing elements (31A to 34A, 31B to 34B) arranged on both sides of the liquid crystal cell and a back light (BL).

[0053] The liquid crystal cell of the bend alignment mode (10) corresponds to the liquid crystal cell shown in Fig. 1. The rubbing directions (RD2, RD3) in the liquid crystal cell (10) are identical (parallel to each other).

[0054] The ellipsoidal polarizing plate comprises a lamination of an optically anisotropic layer (31A, 31B), a transparent substrate (33A, 33B) and a polarizing membrane (34A, 34B) in this order from the side of the liquid crystal cell (10). The rubbing directions (RD1, RD4) of the discotic compound of the optically anisotropic layer (31A, 31B) are antiparallel to the rubbing directions (RD2, RD3) in the liquid crystal cell (10). The rubbing directions (RD1, RD4) of the discotic compounds are antiparallel to the average of directions obtained by projecting normal lines of discotic planes of the discotic compounds on plane of the substrate. The angles between the rubbing directions (RD1, RD4) and the slow axes (SA1, SA2) in plane of the transparent substrates (33A, 33B) are essentially 45° in the same plane. The angles between the rubbing directions (RD1, RD4) and the transmission axes (TA1, TA2) in plane of the polarizing membranes (34A, 34B) are also essentially 45° in the same plane. The polarizing membranes (34A, 34B) are so arranged the transmission axes (TA1, TA2) are perpendicular to each other (crossed nicols arrangement).

[0055] Fig. 5 schematically illustrates a relation of optical compensation in a liquid crystal display of a bend alignment mode.

[0056] As is shown in Fig. 5, the bend alignment liquid crystal cell (10) is optically compensated with cooperation between optically anisotropic layers (31A, 31B) and optically anisotropic transparent substrates (33A, 33B) in the liquid crystal display of the present invention.

[0057] The rubbing directions (RD1, RD4) of the discotic compounds of the optically anisotropic layers (31A, 31B) are antiparallel to the rubbing directions (RD2, RD3) of the liquid crystal cell. Accordingly, the liquid crystal molecules of the bend alignment liquid crystal cell (10) is optically compensated by the corresponding (shown as the relations a to c and e to g) discotic compounds in the optically anisotropic layers (31A, 31B). The optical anisotropic transparent substrates (33A, 33B) correspond (shown as the relations d and h) to the essentially vertically aligned liquid crystal molecule centered in the bend alignment liquid crystal cell (10). The ellipsoids contained in the transparent substrates (33A, 33B) mean refractive index ellipsoids caused by optical anisotropy of the transparent substrates.

[0058] Fig. 6 schematically illustrates a liquid crystal display of a homogeneous alignment mode according to the present invention.

[0059] The liquid crystal display shown in Fig. 6 comprises a liquid crystal cell of a homogeneous alignment mode (20), two polarizing elements (31A to 34A, 31B to 34B) arranged on both sides of the liquid crystal cell and a back light (BL).

[0060] The liquid crystal cell of the homogeneous alignment mode (20) corresponds to the liquid crystal cell shown in Fig. 2. The rubbing directions (RD2, RD3) in the liquid crystal cell (20) are antiparallel to each other.

[0061] The ellipsoidal polarizing plate comprises a lamination of an optically anisotropic layer (31A, 31B), a transparent substrate (33A, 33B) and a polarizing membrane (34A, 34B) in this order from the side of the liquid crystal cell

(20). The rubbing directions (RD1, RD4) of the discotic compound of the optically anisotropic layer (31A, 31B) are antiparallel to the rubbing directions (RD2, RD3) in the liquid crystal cell (20). The rubbing directions (RD1, RD4) of the discotic compounds are antiparallel to the average of directions obtained by projecting normal lines of discotic planes of the discotic compounds on plane of the substrate. The angles between the rubbing directions (RD1, RD4) and the slow axes (SA1, SA2) in plane of the transparent substrates (33A, 33B) are essentially 45° in the same plane. The angles between the rubbing directions (RD1, RD4) and the transmission axes (TA1, TA2) in plane of the polarizing membranes (34A, 34B) are also essentially 45° in the same plane. The polarizing membranes (34A, 34B) are so arranged the transmission axes (TA1, TA2) are perpendicular to each other (crossed nicols arrangement).

[0062] Fig. 7 schematically illustrates a relation of optical compensation in a liquid crystal display of a homogeneous alignment mode.

[0063] As is shown in Fig. 7, the homogeneous alignment liquid crystal cell (20) is optically compensated with cooperation between optically anisotropic layers (31A, 31B) and optically anisotropic transparent substrates (33A, 33B) in the liquid crystal display of the present invention.

[0064] The rubbing directions (RD1, RD4) of the discotic compounds of the optically anisotropic layers (31A, 31B) are antiparallel to the rubbing directions (RD2, RD3) of the liquid crystal cell. Accordingly, the liquid crystal molecules of the bend alignment liquid crystal cell (20) is optically compensated by the corresponding (shown as the relations a to c and e to g) discotic compounds in the optically anisotropic layers (31A, 31B). The optical anisotropic transparent substrates (33A, 33B) correspond (shown as the relations d and h) to the essentially vertically aligned liquid crystal molecule centered in the bend alignment liquid crystal cell (20). The ellipsoids contained in the transparent substrates (33A. 33B) mean refractive index ellipsoids caused by optical anisotropy of the transparent substrates.

[0065] Fig. 8 schematically illustrates various embodiments of an ellipsoidal polarizing plate.

[0066] The embodiment (a1) corresponds to the most basic ellipsoidal polarizing plate shown in Fig. 3. The embodiment (a1) comprises a lamination of an optically anisotropic layer (31) containing discotic compounds, an optically anisotropic transparent substrate (33) and a polarizing membrane (34) in this order. The angle between the rubbing direction (RD) of the discotic compounds and the slow axis (SA) of the transparent substrate (33) is essentially 45°. The slow axis (SA) of the transparent substrate (33) is essentially parallel to the transmission axis (TA) of the polarizing membrane (34).

[0067] The embodiment (a2) comprises a lamination of an optically anisotropic layer (31) containing discotic compounds, an optically anisotropic transparent substrate (33) and a polarizing membrane (34) in this order. The angle between the rubbing direction (RD) of the discotic compounds and the slow axis (SA) of the transparent substrate (33) is essentially 45°. The slow axis (SA) of the transparent substrate (33) is essentially perpendicular to the transmission axis (TA) of the polarizing membrane (34).

[0068] The embodiment (a3) has two transparent substrates (33a, 33b). According to the present invention, at least one substrate (33b) should satisfy the above-described arrangement with an optically anisotropic layer (31) and a polarizing membrane (34). Therefore, the angle between the rubbing direction (RD) of the discotic compounds and the slow axis (SA2) of one transparent substrate (33b) is essentially 45°. The slow axis (SA2) of the transparent substrate (33b) is essentially parallel to the transmission axis (TA) of the polarizing membrane (34). The slow axis (SA1) of the other transparent substrate (33a) is essentially parallel to the rubbing direction (RD) of the discotic compounds in the same manner as in prior art.

[0069] The embodiment (a4) has two transparent substrates (33a, 33b), each of which satisfies the above-described arrangement with an optically anisotropic layer (31) and a polarizing membrane (34). Therefore, the angle between the rubbing direction (RD) of the discotic compounds and the slow axes (SA1, SA2) of the transparent substrates (33a, 33b) is essentially 45°. The slow axes (SA1, SA2) of the transparent substrates (33a, 33b) are essentially parallel to the transmission axis (TA) of the polarizing membrane (34).

[0070] The embodiment (a5) also has two transparent substrates (33a, 33b), each of which satisfies the above-described arrangement with an optically anisotropic layer (31) and a polarizing membrane (34). Therefore, the angle between the rubbing direction (RD) of the discotic compounds and the slow axes (SA1, SA2) of the transparent substrates (33a, 33b) is essentially 45°. The slow axis (SA1) of the transparent substrate (33a) near the optically anisotropic layer (31) is essentially perpendicular to the transmission axis (TA) of the polarizing membrane (34). The slow axis (SA2) of the transparent substrate (33b) near the polarizing membrane (34) is essentially parallel to the transmission axis (TA) of the polarizing membrane (34).

[0071] Fig. 9 schematically illustrates other various embodiments of an ellipsoidal polarizing plate.

[0072] The embodiment (b1) comprises a lamination of an optically anisotropic transparent substrate (33), an optically anisotropic layer (31) containing discotic compounds and a polarizing membrane (34) in this order. The angle between the rubbing direction (RD) of the discotic compounds and the slow axis (SA) of the transparent substrate (33) is essentially 45°. The slow axis (SA) of the transparent substrate (33) is essentially parallel to the transmission axis (TA) of the polarizing membrane (34).

[0073] The embodiment (b2) comprises a lamination of an optically anisotropic transparent substrate (33), an optically

anisotropic layer (31) containing discotic compounds and a polarizing membrane (34) in this order. The angle between the rubbing direction (RD) of the discotic compounds and the slow axis (SA) of the transparent substrate (33) is essentially 45°. The slow axis (SA) of the transparent substrate (33) is essentially perpendicular to the transmission axis (TA) of the polarizing membrane (34).

[0074] The embodiment (b3) has two transparent substrates (33a, 33b). According to the present invention, at least one substrate (33b) should satisfy the above-described arrangement with an optically anisotropic layer (31) and a polarizing membrane (34). Therefore, the angle between the rubbing direction (RD) of the discotic compounds and the slow axis (SA2) of one transparent substrate (33b) is essentially 45°. The slow axis (SA2) of the transparent substrate (33b) is essentially parallel to the transmission axis (TA) of the polarizing membrane (34). The slow axis (SA1) of the other transparent substrate (33a) is essentially parallel to the rubbing direction (RD) of the discotic compounds in the same manner as in prior art.

[0075] The embodiment (b4) has two transparent substrates (33a, 33b), each of which satisfies the above-described arrangement with an optically anisotropic layer (31) and a polarizing membrane (34). Therefore, the angle between the rubbing direction (RD) of the discotic compounds and the slow axes (SA1, SA2) of the transparent substrates (33a, 33b) is essentially 45°. The slow axes (SA1, SA2) of the transparent substrates (33a, 33b) are essentially parallel to the transmission axis (TA) of the polarizing membrane (34).

[0076] The embodiment (b5) also has two transparent substrates (33a, 33b), each of which satisfies the above-described arrangement with an optically anisotropic layer (31) and a polarizing membrane (34). Therefore, the angle between the rubbing direction (RD) of the discotic compounds and the slow axes (SA1, SA2) of the transparent substrates (33a, 33b) is essentially 45°. The slow axis (SA1) of the outermost transparent substrate (33a) is essentially perpendicular to the transmission axis (TA) of the polarizing membrane (34). The slow axis (SA2) of the transparent substrate (33b) near the optically anisotropic layer (31) and the polarizing membrane (34) is essentially parallel to the transmission axis (TA) of the polarizing membrane (34).

[Optical characteristics of ellipsoidal polarizing plate]

[0077] The ellipsoidal polarizing plate comprises an optically anisotropic layer containing discotic compounds, an optically anisotropic transparent substrate and a polarizing membrane.

[0078] The optical anisotropic layer has a direction of the minimum retardation, which is preferably not present in plane of the layer, and is also preferably not present along a normal line of the layer. The optically anisotropic layer also preferably does not have a direction in which the retardation value is 0 (optical axis).

[0079] The important optical characteristics of the optical anisotropic layer and the transparent support include the Re retardation value defined by the formula (1) and the Rth retardation value defined by the formula (2a) or (2b).

$$(1) \qquad Re = (nx-ny)\times d$$

$$(2a) \qquad Rth = [(n2+n3)/2-n1]\times d$$

$$(2b) \qquad Rth = [(nx+ny)/2-nz]\times d$$

in which nx is a refractive index of a slow axis in plane of the optically anisotropic layer or the transparent substrate; ny is a refractive index of a fast axis in plane of the optically anisotropic layer or the transparent substrate; nl is the minimum principal refractive index of the optically anisotropic layer; each of n2 and n3 is the other principal refractive index of the optically anisotropic layer; nz is a refractive index of a thickness direction of the optically anisotropic layer or the transparent substrate; and d is a thickness of the optically anisotropic layer or the transparent substrate.

[0080] The Re retardation value of the optically anisotropic layer is preferably in the range of 10 to 100 nm. The Rth retardation value of the optically anisotropic layer is preferably in the range of 40 to 200 nm. The angle between a direction of the minimum retardation and a normal line in the optically anisotropic layer (β) is preferably in the range of 20 to 50°.

[0081] The preferred range of the retardation value of the transparent substrate depends on whether the ellipsoidal polarizing plate is used in a liquid crystal display of a bend alignment mode or a homogeneous alignment mode.

[0082] In the case that the ellipsoidal polarizing plate is used in a liquid crystal display of a bend alignment mode, the Re retardation value of the transparent substrate (or a lamination of the substrate where two or more substrates in combination) is preferably in the range of 5 to 100 nm, and the Rth retardation value is preferably in the range of 100 to 1,000 nm.

[0083] In the case that the ellipsoidal polarizing plate is used in a liquid crystal display of a homogeneous alignment mode, the Re retardation value of the transparent substrate (or a lamination of the substrate where two or more substrates in combination) is preferably in the range of 0 to 100 nm, and the Rth retardation value is preferably in the range of 10 to 1,000 nm.

[0084] In the case that two or more transparent substrates are used (particularly in a liquid crystal display of a bend alignment mode), a cellulose ester film and a polycarbonate film are preferably used in combination.

[0085] The Re retardation value of the cellulose ester film used in a liquid crystal display of a bend alignment mode is preferably in the range of 0 to 30 nm, and the Rth retardation value is preferably in the range of 10 to 100 nm. The Re retardation value of the polycarbonate film is preferably in the range of 5 to 100 nm, and the Rth retardation value is preferably in the range of 100 to 1,000 nm.

[0086] The liquid crystal display of the present invention is characterized in that the wavelength dependency of the optically compensatory effect is low. The low wavelength dependency of the optically compensatory effect means that the difference between the sum of the Re retardation values of the optically anisotropic layer and the transparent substrate (total value of the layer and the substrates where two ellipsoidal polarizing plates are used) and the Re retardation value of the liquid crystal display is less than 10 nm even if the values are measured at any wavelength in the range of 400 to 700. The values can easily be obtained by arranging the optically anisotropic layer, the transparent substrate and the polarizing membrane of the ellipsoidal polarizing plate according to the present invention.

[Optically anisotropic layer]

[0087] The optically anisotropic layer contains a discotic compound. The discotic compound preferably is negative uniaxial, and preferably is obliquely aligned. The discotic compound preferably has a hybrid alignment shown in Fig. 3, wherein the inclined angles (between the discotic planes and the planes parallel to the transparent substrate) are changed along a normal line of the transparent substrate. The discotic compound has an optic axis along a normal line of the discotic plane. The birefringence along the discotic plane is larger than that along the optic axis.

[0088] An optically anisotropic layer is preferably formed by aligning a discotic compound by an orientation layer, and fixing the alignment of the discotic compound. The discotic compound is fixed preferably by a polymerization reaction.

[0089] The minimum retardation value in the optically anisotropic layer is preferably larger than 0. In other words, a direction having retardation of 0 preferably is not present in the optically anisotropic layer.

[0090] The discotic (liquid crystal) compound is described in various documents (C. Destrade et al., Mol. Crysr. Liq. Cryst., vol. 71, page 111 (1981); Japan Chemical Society, Quarterly Chemical Review (written in Japanese), chapter 5 and chapter 10, section 2 (1994); B. Kohne et al., Angew. Chem. Soc. Chem. Comm., page 1794 (1985); and J. Zhang et al., J. Am. Chem. Soc., vol. 116, page 2655 (1994)). The polymerization reaction of the discotic compound is described in Japanese Patent Provisional Publication No. 8(1996)-27284.

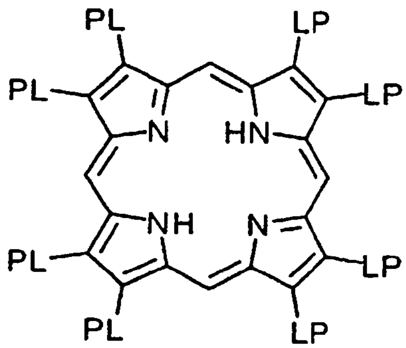
[0091] A polymerizable group should be bound to a discotic core of the discotic compound to cause the polymerization reaction of the compound. However, if the polymerizable group is directly bound to the discotic core, it is difficult to keep the alignment at the polymerization reaction. Therefore, a linking group is introduced between the discotic core and the polymerizable group. Accordingly, the discotic compound having a polymerizable group preferably is a compound represented by the following formula (I).

$$\text{(I)} \qquad D(\text{-}L\text{-}P)_n$$

in which D is a discotic core; L is a divalent linking group; P is a polymerizable group; and n is an integer of 4 to 12.

[0092] Examples of the discotic cores (D) are shown below. In the examples, LP (or PL) means the combination of the divalent linking group (L) and the polymerizable group (P).

(D1)



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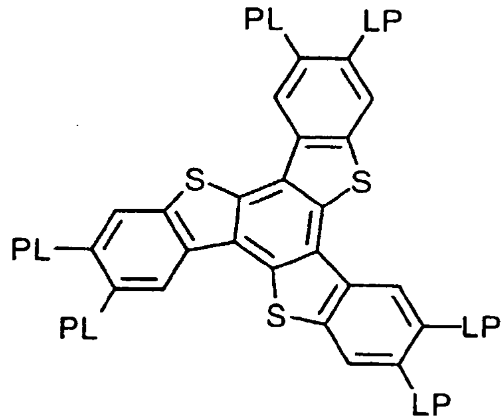

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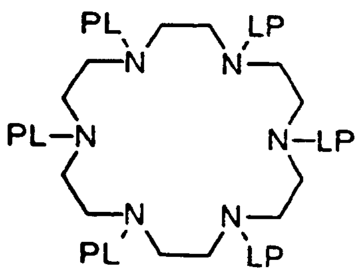

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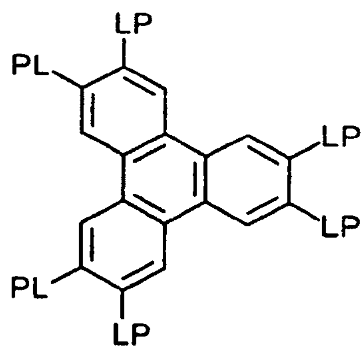

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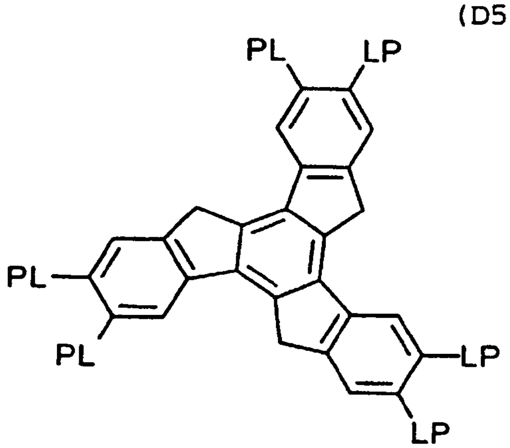

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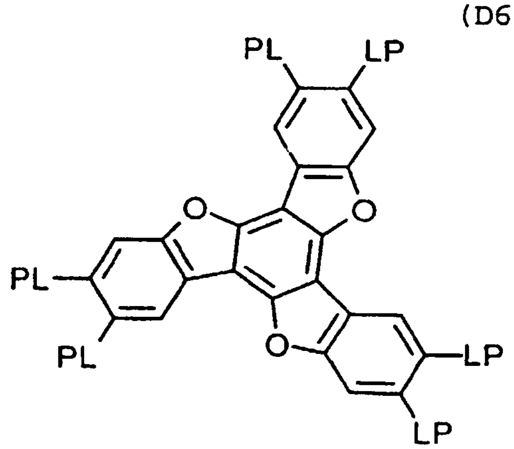

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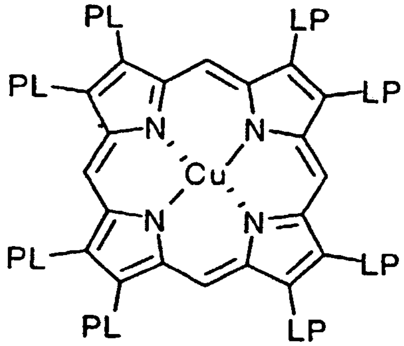
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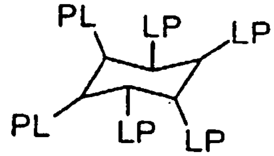
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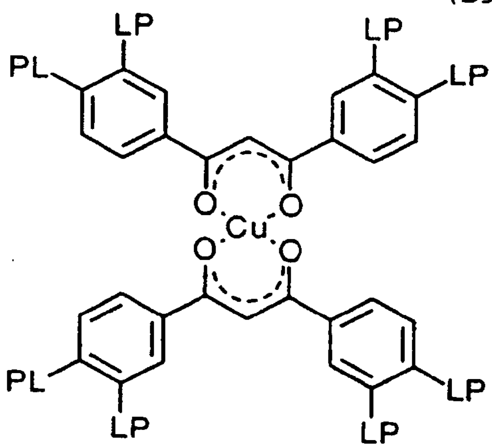
(D9)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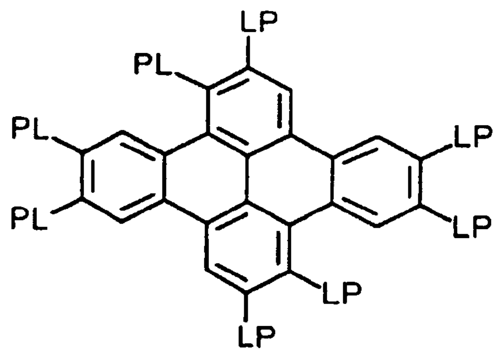
(D10)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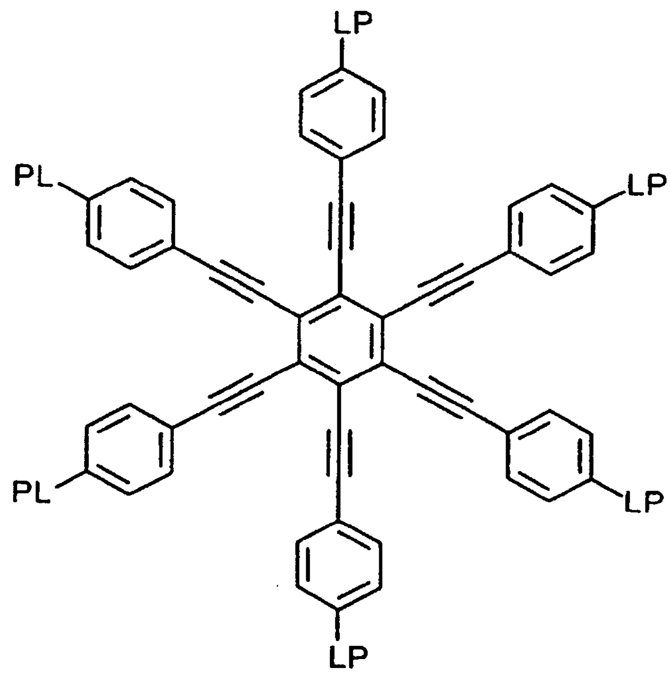
(D11)



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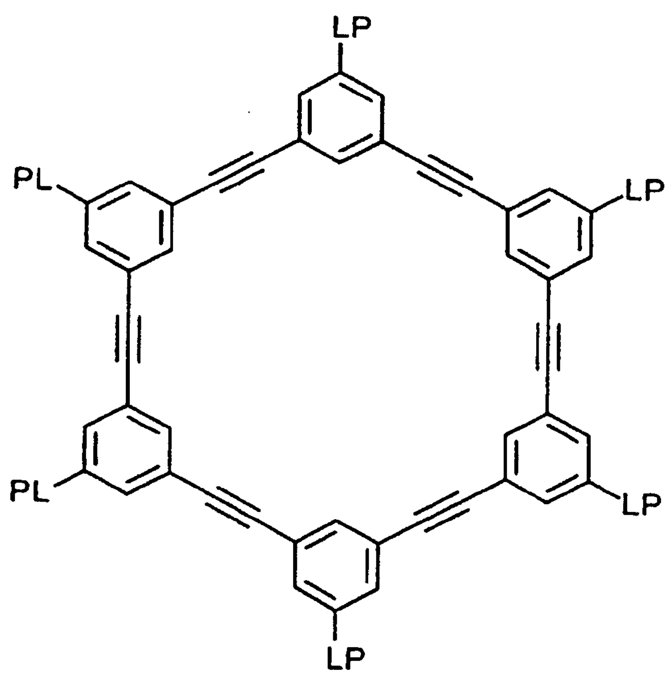

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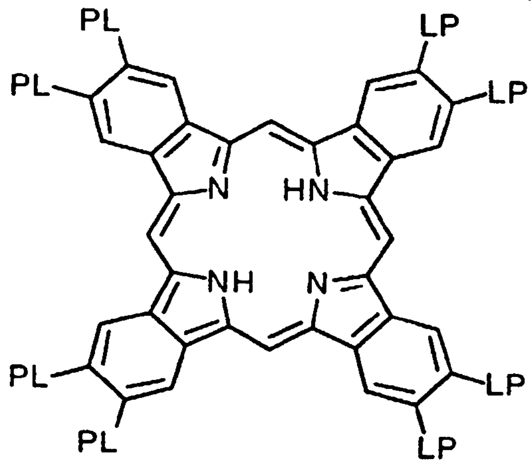

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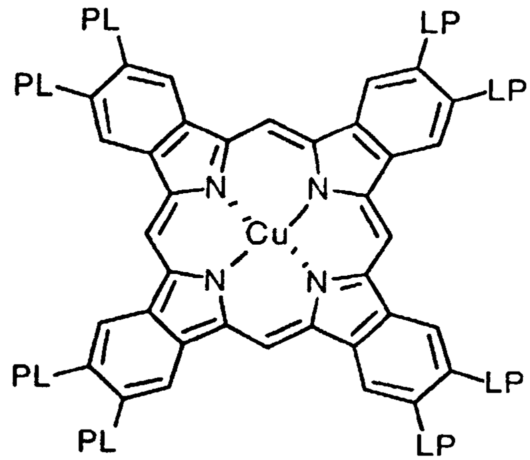

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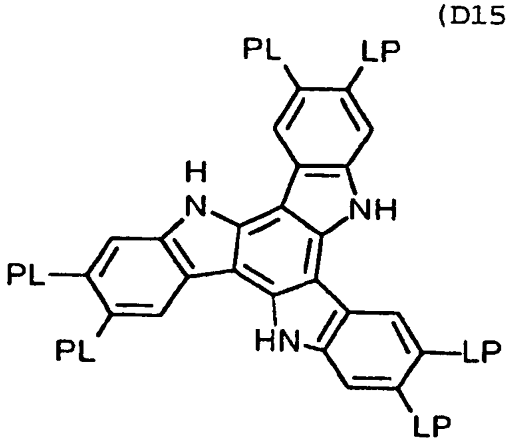


[0093] In the formula (I), the divalent linking group (L) preferably is selected from the group consisting of an alkylene group, an alkenylene group, an arylene group, -CO, -NH-, -O-, -S- and combinations thereof. L more preferably is a divalent linking group comprising at least two divalent groups selected from the group consisting of an alkylene group, an arylene group, -CO-, -NH-, -O- and -S-. L more preferably is a divalent linking group comprising at least two divalent groups selected from the group consisting of an alkylene group, an arylene group, -CO- and -O-. The alkylene group preferably has 1 to 12 carbon atoms. The alkenylene group preferably has 2 to 12 carbon atoms. The arylene group preferably has 6 to 10 carbon atoms.

[0094] Examples of the divalent linking groups (L) are shown below. In the examples, the left side is attached to the discotic core (D), and the right side is attached to the polymerizable group (P). The AL means an alkylene group or an alkenylene group. The AR means an arylene group. The alkylene group, the alkenylene group and the arylene group may have a substituent group (e.g., an alkyl group).

L1: -AL-CO-O-AL-O-CO-
L2: -AL-CO-O-AL-O-
L3: -AL-CO-O-AL-O-AL-
L4: -AL-CO-O-AL-O-CO-
L5: -CO-AR-O-AL-
L6: -CO-AR-O-AL-O-
L7: -CO-AR-O-AL-O-CO-
L8: -CO-NH-AL-
L9: -NH-AL-O-

L10: -NH-AL-O-CO-
L11: -O-AL-
L12: -O-AL-O-
L13: -O-AL-O-CO-
L14: -O-AL-O-CO-NH-AL-
L15: -O-AL-S-AL-
L16: -O-CO-AR-O-AL-CO-
L17: -O-CO-AR-O-AL-O-CO-
L18: -O-CO-AR-O-AL-O-AL-O-CO-
L19: -O-CO-AR-O-AL-O-AL-O-AL-O-CO-
L20: -S-AL-
L21: -S-AL-O-
L22: -S-AL-O-CO-
L23: -S-AL-S-AL-
L24: -S-AR-AL-

[0095] The polymerizable group (P) is determined by the polymerization reaction. Examples of the polymerizable groups (P) are shown below.

(P1) $—CH{=}CH_2$

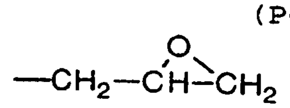
(P2) $—C{\equiv}CH$

(P3) $—CH_2—C{\equiv}CH$

(P4) $—NH_2$

(P5) $—SO_3H$

(P6)



(P7) $—C(CH_3){=}CH_2$

(P8) $—CH{=}CH—CH_3$

(P9) $—N{=}C{=}S$

(P10) $—SH$

(P11) $—CHO$

(P12) $—OH$

(P13) $—CO_2H$

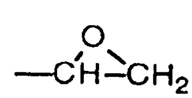
(P14) $—N{=}C{=}O$

(P15) $—CH{=}CH—C_2H_5$

(P16) $—CH{=}CH—n\text{-}C_3H_7$

(P17) $—CH{=}C(CH_3)—CH_3$

(P18)



[0096] The polymerizable group (P) preferably is an unsaturated polymerizable group (P1, P2, P3, P7, P8, P15, P16, P17) or an epoxy group (P6, P18), more preferably is an unsaturated polymerizable group, and most preferably is an ethylenically unsaturated group (P1, P7, P8, P15, P16, P17).

[0097] In the formula (I), n is an integer of 4 to 12, which is determined by the chemical structure of the discotic core (D). The 4 to 12 combinations of L and P can be different from each other. However, the combinations are preferably

identical.

[0098] An optically anisotropic layer can be formed by coating a solution containing the discotic compound, a polymerization initiator and other optional components on an orientation layer.

[0099] The optically anisotropic layer has a thickness preferably in the range of 0.5 to 100 μm, and more preferably in the range of 0.5 to 30 μm.

[0100] The aligned discotic compound is preferably fixed while keeping the alignment. The compound is fixed preferably by a polymerization reaction. The polymerization reaction can be classified a thermal reaction using a thermal polymerization initiator and a photo reaction using a photo polymerization initiator. A photo polymerization reaction is preferred.

[0101] Examples of the photo polymerization initiators include α-carbonyl compounds (described in U.S. Patent Nos. 2,367,661, 2,367,670), acyloin ethers (described in U.S. Patent No. 2,448,828), α-hydrocarbon substituted acyloin compounds (described in U.S. Patent No. 2,722,512), polycyclic quinone compounds (described in U.S. Patent Nos. 2,951,758, 3,046,127), combinations of triarylimidazoles and p-aminophenyl ketones (described in U.S. Patent No. 3,549,367). acridine or phenazine compounds (described in Japanese Patent Provisional Publication No. 60(1985)-105667 and U.S. Patent No. 4,239,850) and oxadiazole compounds (described in U.S. Patent No. 4,212,970).

[0102] The amount of the photo polymerization initiator is preferably in the range of 0.01 to 20 wt.%, and more preferably in the range of 0.5 to 5 wt.% based on the solid content of the coating solution of the layer.

[0103] The light irradiation for the photo polymerization is preferably conducted by an ultraviolet ray. The exposure energy is preferably in the range of 20 to 5,000 mJ per cm^2, and more preferably in the range of 100 to 800 mJ per cm^2. The light irradiation can be conducted while heating the layer to accelerate the photo polymerization reaction.

[0104] A protective layer can be provided on the optical anisotropic layer.

[Orientation layer]

[0105] The orientation layer has a function of aligning discotic compounds. The orientation layer can be formed by rubbing treatment of an organic compound (preferably a polymer), oblique evaporation of an inorganic compound, formation of a micro groove layer, or stimulation of an organic compound (e.g., ω-tricosanoic acid, dioctadecylmethylammonium chloride, methyl stearate) according to a Langmuir-Blodgett method. Further, the aligning function of the orientation layer can be activated by applying an electric or magnetic field to the layer or irradiating the layer with light.

[0106] The orientation layer is preferably formed by rubbing a polymer The polymer preferably is polyvinyl alcohol. A denatured polyvinyl alcohol having a hydrophobic group is particularly preferred. The discotic compound can uniformly be aligned by introducing the hydrophobic group into polyvinyl alcohol because the hydrophobic group has an affinity with the discotic compound. The hydrophobic group is attached to the side chain or the end of the main chain of polyvinyl alcohol.

[0107] The hydrophobic group preferably is an aliphatic group (more preferably an alkyl group or an alkenyl group) having 6 or more carbon atoms or an aromatic group.

[0108] In the case that the hydrophobic group is attached to the end of the main chain, a linking group is preferably introduced between the hydrophobic group and the end of the main chain. Examples of the linking group include -S-, -C(CN)R^1-, -NR^2-, -CS- and combinations thereof. Each of R^1 and R^2 is hydrogen or an alkyl group having 1 to 6 carbon atoms, and preferably is an alkyl group having 1 to 6 carbon atoms.

[0109] In the case that the hydrophobic group is attached to the side chain, the acetyl group of the vinyl acetate units in polyvinyl alcohol is partially replaced with an acyl group (-CO-R^3) having 7 or more carbon atoms. R^3 is an aliphatic group having 6 or more carbon atoms or an aromatic group.

[0110] Commercially available denatured polyvinyl alcohols (e.g., MP103, MP203, R1130, Kuraray Co., Ltd.) can be used in the orientation layer.

[0111] The (denatured) polyvinyl alcohol has a saponification degree preferably of not smaller than 80%. The (denatured) polyvinyl alcohol has a polymerization degree preferably of not smaller than 200.

[0112] The rubbing treatment can be conducted by rubbing the layer with a paper or cloth several times along a certain direction. A cloth is preferred to a paper. The cloth preferably uniformly contains uniform (about length and thickness) fibers.

[0113] After aligning discotic compounds of the optically anisotropic layer by the orientation layer, the alignment of the discotic compounds can be kept even if the orientation layer is removed. Therefore, the orientation layer is not essential in a prepared ellipsoidal polarizing plate, while the orientation layer is essential in the preparation of the ellipsoidal polarizing plate.

[0114] In the case that the orientation layer is provided between the optically anisotropic layer and a transparent support, an undercoating layer (an adhesive layer) is preferably provided between the orientation layer and the transparent support.

[Transparent substrate]

[0115] A transparent substrate preferably is a polymer film made of a transparent polymer of positive inherent birefringence. The transparent substrate means that light transmittance is not less than 80%.
[0116] A polymer film made of a polymer of positive inherent birefringence usually has a (negative) refractive index ellipsoid. The film has one or two optic axes along a normal line of the film. In the present invention, the above-mentioned polymer film is preferably used as the substrate in combination with an optical anisotropic layer containing a discotic compound, which has a negative inherent birefringence and an optical axis along a normal line of a discotic plane.
[0117] Examples of the polymers include polycarbonate, polyarylate, polysulfone, polyethersulfone and cellulose ester (e.g., diacetyl cellulose, triacetyl cellulose). Polycarbonate and cellulose ester are preferred. The polymer film is formed preferably according to a solvent casting method.
[0118] A lamination of two or more transparent substrates can be used in the ellipsoidal polarizing plate. In the case that two or more transparent substrates are used (particularly in a liquid crystal display of a bend alignment mode), a cellulose acetate film (particularly a triacetyl cellulose film) and a polycarbonate film are preferably used in combination. The lamination preferably comprises a cellulose ester film and a polycarbonate film in this order from the side of an optical anisotropic layer.
[0119] The slow axis of the transparent substrate corresponds to a stretching direction of a polymer film. Even if a specific stretching treatment is not conducted, a polymer film is naturally stretched along a longitudinal direction of a polymer roll. The effect of the present invention can be obtained by an optical anisotropy of the naturally stretched film.
[0120] The transparent substrate has a thickness preferably in the range of 20 to 500 μm, and more preferably in the range of 50 to 200 μm.
[0121] The transparent substrate can be subjected to a surface treatment (e.g., glow discharge treatment, corona discharge treatment, ultraviolet (UV) treatment, flame treatment) to improve adhesion to a layer formed on the substrate (e.g., adhesive layer, orientation layer, optically anisotropic layer). A glow discharge treatment or a corona discharge treatment is preferred. Two or more surface treatments can be used in combination.
[0122] An adhesive layer (undercoating layer) can be provided on the transparent substrate. The adhesive layer is preferably formed by coating a hydrophilic polymer (e.g., gelatin) on the transparent substrate. The adhesive layer has a thickness preferably in the range of 0.1 to 2 μm, and more preferably in the range of 0.2 to 1 μm.
[0123] A protective layer can be provided on the back surface of the transparent substrate.

[Polarizing membrane]

[0124] An iodine type polarizing membrane, a (dichroic) dye type polarizing membrane or a polyene type polarizing membrane can be used in the present invention. The iodine type polarizing membrane and the dye type polarizing membrane is usually made of a polyvinyl alcohol film.
[0125] The transmission axis of the polarizing membrane is perpendicular to the stretching direction of the film.
[0126] The polarizing membrane is usually attached to a protective membrane. In the present invention, the transparent substrate can function as the protective membrane. In the case that a protective membrane is used in addition to the transparent substrate, the protective membrane preferably is an optically isotropic film such as a cellulose ester film, particularly a triacetyl cellulose film. In the case that the ellipsoidal polarizing plate of the present invention is used as only one of two polarizing elements, the other polarizing element preferably is a lamination of a polarizing membrane and a protective membrane.

[Preparation of ellipsoidal polarizing plate]

[0127] The ellipsoidal polarizing plate can be successively prepared in the following manner.
[0128] First, an orientation layer is formed on a transparent substrate. A rubbing treatment is conducted on the orientation layer. The angle between the rubbing direction and the direction of transferring the transparent substrate (corresponding to the slow axis) is adjusted to 45°. An optically anisotropic layer is formed on the orientation layer. The lamination is rolled up. While rolling the lamination down, the surface of the optically anisotropic layer is covered with a protective film, which protects optically anisotropic layer from scratch or dust. The lamination is rolled up again.
[0129] In the case that two transparent substrates are used, a second transparent substrate is attached on a surface of a first substrate of a rolled film by using an adhesive. In the case that three or more transparent substrates are used, the process is repeated by using an adhesive.
[0130] Finally, a polarizing membrane is attached on a surface of the outermost substrate by using an adhesive.
[0131] The attachment of the lamination film, the second substrate and the polarizing membrane is preferably conducted immediately after forming the optically anisotropic layer to reduce the repeating number of the processes of rolling the film up and down.

[Liquid crystal cell]

[0132] The ellipsoidal polarizing plate of the present invention is particularly effective in a liquid crystal display of a bend alignment mode or a homogeneous alignment mode.

[0133] In a liquid crystal cell of a bend alignment mode, liquid crystal molecules centered in the cell can be twisted (chiral alignment).

[0134] In the liquid crystal cell of a bend alignment mode, the product (Δn×d) of a refractive anisotropy (Δn) of the liquid crystal molecule and a thickness (d) of the liquid crystal layer of the liquid crystal cell is preferably in the range of 100 to 2 000 nm more preferably in the range of 150 to 1,700 nm, and most preferably in the range of 500 to 1,500 nm to satisfy the brightness and the viewing angle.

[0135] In the liquid crystal cell of a homogeneous alignment mode, the product (Δn×d) of a refractive anisotropy (Δn) of the liquid crystal molecule and a thickness (d) of the liquid crystal layer of the liquid crystal cell is preferably in the range of 100 to 2 000 nm. more preferably in the range of 100 to 1,000 nm, and most preferably in the range of 100 to 700 nm to satisfy the brightness and the viewing angle.

[0136] The liquid crystal cell of a vertical alignment mode or a homogeneous alignment mode is used according to a normally white (NW) mode or a normally black (NB) mode.

EXAMPLE 1

(Formation of first transparent substrate)

[0137] On a triacetyl cellulose film (thickness: 100 μm), a gelatin undercoating layer (thickness: 0.1 μm) was formed to obtain a first transparent substrate

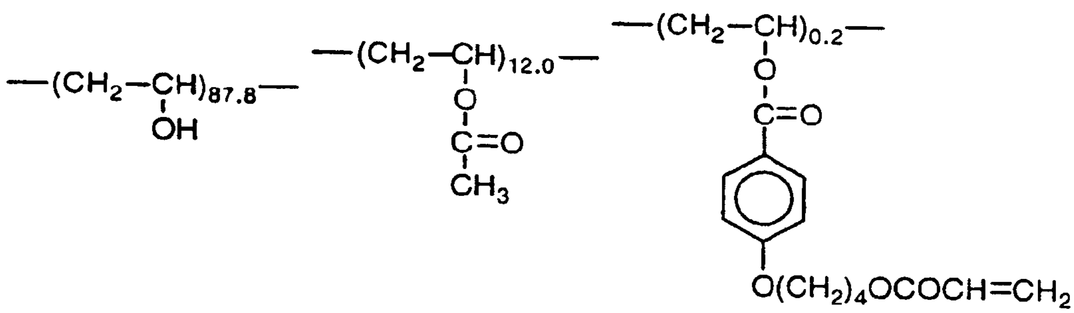
[0138] The Re retardation value of the first transparent substrate (measured at the wavelength of 546 nm) was 0.6 nm and the Rth retardation value was 35 nm.

(Formation of orientation layer)

[0139] A coating solution of the following composition was coated on the gelatin undercoating layer of the first transparent substrate by using a wire bar coater of #16. The coating amount was 28 ml per m^2. The coated layer was air dried at 60°C for 60 seconds and further air dried at 90°C for 150 seconds to form an orientation layer. The formed layer was subjected to a rubbing treatment. The angle between the rubbing direction and the slow axis of the first transparent substrate (measured at the wavelength of 632.8 nm) was 45°.

Coating solution for orientation layer	
The following denatured polyvinyl alcohol	10 weight parts
Water	371 weight parts
Methanol	119 weight parts
Glutaric aldehyde (cross-linking agent)	0.5 weight part

(Denatured polyvinyl alcohol)

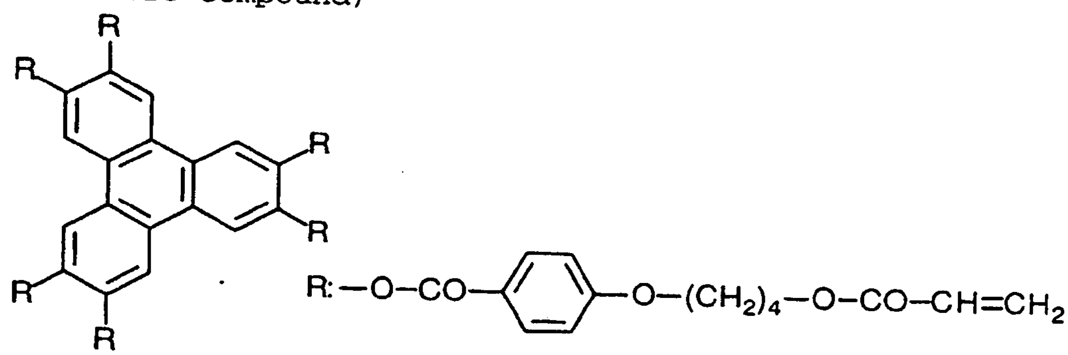


(Formation of optically anisotropic layer)

[0140] In 102 g of methyl ethyl ketone, 41.01 g of the following discotic (liquid crystal) compound, 4.06 g of trimethylolpropane triacrylate denatured with ethylene oxide (V#360, Osaka Organic Chemical Co., Ltd.), 0.90 g of cellulose acetate butyrate (CAB551-0.2, Eastman Chemical), 0.23 g of cellulose acetate butyrate (CAB531-1, Eastman Chemical), 1.35 g of a photopolymerization initiator (Irgacure 907, Ciba-Geigy) and 0.45 g of a sensitizer (Kayacure DETX, Nippon Kayaku Co., Ltd.) were dissolved to prepare a coating solution. The coating solution was coated on the orientation layer by using a wire bar of #3. The sheet was adhered to a metal frame, and heated in a thermostat at 130°C for 2 minutes to align the discotic compound. The sheet was irradiated with an ultraviolet ray at 130°C for 1 minute by using a high pressure mercury lamp of 120 W per cm. The sheet was cooled to room temperature to form an optically anisotropic layer.

[0141] The Re retardation value of the optically anisotropic layer (measured at the wavelength of 546 nm) was 38 nm. The average inclined angle of the discotic plane based on the surface of the first transparent substrate was 40°.

(Discotic compound)



(Formation of second transparent substrate)

[0142] In dichloromethane, 2,2'-bis(4-hydroxyphenyl)propane polycarbonate resin (viscosity average molecular weight: 28,000) was dissolved to obtain a 18 wt.% solution. The obtained solution was defoamed under vacuum to obtain a dope. The dope was cast on a band, dried at 50°C for 10 minutes, peeled from the band, and further dried at 100°C for 10 minutes. The obtained film was stretched by 3.3% along a longitudinal direction at 170°C, and was stretched by 4.7% along a horizontal direction to obtain a biaxially stretched roll film (second transparent substrate) having the thickness of 80 μm. The longitudinal stretching was controlled by the difference between the rotating speeds of two chucking rolls. The horizontal stretching was controlled by the width of a tenter.

[0143] The Re retardation value of the second transparent substrate (measured at the wavelength of 546 nm) was 3 nm, and the Rth retardation value was 200 nm.

(Lamination of second transparent substrate)

[0144] On the surface of the first transparent substrate of the lamination (comprising the optically anisotropic layer and the first transparent substrate), the second transparent substrate was laminated by using an adhesive. The slow axis of the second transparent substrate (measured at the wavelength of 632.8 nm) was perpendicular to the slow axis of the first transparent substrate.

[0145] The Re retardation value of the obtained lamination was measured at the wavelength of 436 nm, 546 nm and 611.5 nm.

(Formation of ellipsoidal polarizing plate)

[0146] On the surface of the second transparent substrate of the lamination (comprising the optically anisotropic layer and the first and second transparent substrates), a polarizing membrane was laminated by using an adhesive. The transmission axis of the polarizing membrane was perpendicular to the slow axis of the first transparent substrate, and parallel to the slow axis of the second transparent substrate.

EXAMPLE 2

(Formation of second transparent substrate)

[0147] In dichloromethane, 2,2'-bis(4-hydroxyphenyl)propane polycarbonate resin (viscosity average molecular weight: 28,000) was dissolved to obtain a 18 wt.% solution. The obtained solution was defoamed under vacuum to obtain a dope. The dope was cast on a band. dried at 50°C for 10 minutes, peeled from the band, and further dried at 100°C for 10 minutes. The obtained film was stretched by 5.5% along a longitudinal direction at 170°C, and was stretched by 2.5% along a horizontal direction to obtain a biaxially stretched roll film (second transparent substrate) having the thickness of 80 μm. The longitudinal stretching was controlled by the difference between the rotating speeds of two chucking rolls. The horizontal stretching was controlled by the width of a tenter.
[0148] The Re retardation value of the second transparent substrate (measured at the wavelength of 546 nm) was 30 nm, and the Rth retardation value was 200 nm.

(Lamination of second transparent substrate)

[0149] On the surface of the first transparent substrate of the lamination (comprising the optically anisotropic layer and the first transparent substrate) prepared in Example 1, the second transparent substrate was laminated by using an adhesive. The slow axis of the second transparent substrate (measured at the wavelength of 632.8 nm) was perpendicular to the slow axis of the first transparent substrate.
[0150] The Re retardation value of the obtained lamination was measured at the wavelength of 436 nm, 546 nm and 611.5 nm.

(Formation of ellipsoidal polarizing plate)

[0151] On the surface of the second transparent substrate of the lamination (comprising the optically anisotropic layer and the first and second transparent substrates), a polarizing membrane was laminated by using an adhesive. The transmission axis of the polarizing membrane was perpendicular to the slow axis of the first transparent substrate, and parallel to the slow axis of the second transparent substrate.

COMPARISON EXAMPLE 1

(Formation of orientation layer)

[0152] The coating solution used in Example 1 was coated on the gelatin undercoating layer of the first transparent substrate prepared in Example 1 by using a wire bar coater of #16. The coating amount was 28 ml per m². The coated layer was air dried at 60°C for 60 seconds, and further air dried at 90°C for 150 seconds to form an orientation layer. The formed layer was subjected to a rubbing treatment. The rubbing direction was parallel to the slow axis of the first transparent substrate (measured at the wavelength of 632.8 nm).

(Formation of ellipsoidal polarizing plate)

[0153] An ellipsoidal polarizing plate was prepared in the same manner as in Example 1, except that the above-prepared orientation layer was used.
[0154] The Re retardation value of the lamination comprising the optically anisotropic layer and the first and second transparent substrates was measured at the wavelength of 436 nm, 546 nm and 611.5 nm.

(Optical characteristics of ellipsoidal polarizing plates)

[0155] The optical characteristics of the ellipsoidal polarizing plates prepared in Examples 1 & 2 and Comparison Example 1 are shown in the following Table 1.

TABLE 1

Sample	OA layer		First substrate				Second substrate			
	Re	β	Re	Rth	θ	α	Re	Rth	θ	α
Ex.1	38	40	0.6	35	45	90	3	200	45	0

TABLE 1 (continued)

Sample	OA layer		First substrate				Second substrate			
	Re	β	Re	Rth	θ	α	Re	Rth	θ	α
Ex.2	38	40	0.6	35	45	90	30	200	45	0
C1	38	40	0.6	35	0	45	3	200	90	45

(Remark)
C Comparison Example
OA Optically anisotropic
Re Re retardation value (nm)
Rth Rth retardation value (nm)
β Average inclined angle (°) of discotic plane
θ Angle (°) between the average of directions obtained by projecting normal lines of discotic planes of the discotic compounds on plane of the substrate (rubbing direction) and the slow axis of the transparent substrate (90° means perpendicular and 0° means parallel)
α Angle (°) between the slow axis of the transparent substrate and the transmission axis of the polarizing membrane (90° means perpendicular and 0° means parallel)

EXAMPLE 3

(Formation of liquid crystal cell of bend alignment mode)

[0156] On a glass plate having an ITO electrode, a polyimide film (orientation layer) was attached, and subjected to a rubbing treatment The two glass plates were placed by facing the orientation layer with each other. The rubbing direction on one glass plate was parallel to the rubbing direction on the other plate. The cell gap was 6 μm. A liquid crystal molecule having Δn of 0 1396 (ZLI1132, Merck & Co., Inc.) was injected into the cell gap to prepare a liquid crystal cell of a bend alignment mode

[0157] The Re retardation value of the liquid crystal cell was measured at the wavelength of 436 nm, 546 nm and 611 5 nm while applying voltage (5 or 5 5 V) of a square wave (55 Hz) to the cell.

(Preparation of liquid crystal display)

[0158] Two ellipsoidal polarizing plates prepared in Example 1 were arranged on both sides of the liquid crystal cell of a bend alignment mode The optically anisotropic layer of the ellipsoidal polarizing plate was faced with the glass plate of the liquid crystal cell The rubbing direction of the orientation layer of the liquid crystal cell was antiparallel to the rubbing direction of the orientation layer of the optically anisotropic layer.

EXAMPLE 4

(Preparation of liquid crystal display)

[0159] Two ellipsoidal polarizing plates prepared in Example 2 were arranged on both sides of the liquid crystal cell of a bend alignment mode prepared in Example 3. The optically anisotropic layer of the ellipsoidal polarizing plate was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was antiparallel to the rubbing direction of the orientation layer of the optically anisotropic layer.

COMPARISON EXAMPLE 2

(Preparation of liquid crystal display)

[0160] Two ellipsoidal polarizing plates prepared in Comparison Example 1 were arranged on both sides of the liquid crystal cell of a bend alignment mode prepared in Example 3. The optically anisotropic layer of the ellipsoidal polarizing plate was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was antiparallel to the rubbing direction of the orientation layer of the optically anisotropic layer.

(Evaluation of liquid crystal displays)

[0161] The difference between the Re retardation values of the lamination (the optically anisotropic layer and the first and second transparent substrates) and the liquid crystal cell was calculated. The wavelength dependency was evaluated as the differences measured at the wavelength of 436 nm, 546 nm and 611.5. The results are set forth in Table 2. In Table 2, the wavelength dependency is shown as a relative value based on the result measured at the wavelength of 546 nm as the standard value (0).

[0162] Voltage (55 Hz) of a square wave was applied to the liquid crystal cell of the liquid crystal displays prepared in Examples 3 & 4 and Comparison Example 2. An image was displayed according to a normally white mode (white: 2V, black: 5V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured. The viewing angle was evaluated as an angle that can view an image having a contrast ratio of not smaller than 10.

[0163] Further, the front chromaticity of the black image was measured.

[0164] Furthermore, the transmittance of the liquid crystal display was measured at the wavelength of 436 nm. The result was evaluated as a relative value based on the transmittance of a lamination of two polarizing membranes (para nicols arrangement) measured at the wavelength of 436 nm as the standard value (100%).

TABLE 2

Sample	Dependency			Viewing angle				Chromat.		T
	436	546	611.5	U	D	L	R	x	y	(%)
Ex.3	6.0	0	-1.2	80+	59	57	57	0.151	0.204	1.10
Ex 4	6.2	0	-1.0	80+	70	73	73	0.150	0.205	1.08
C2	20.2	0	-6.4	80+	60	58	57	0.094	0.120	3.86

(Remark)
C Comparison Example
U Upward viewing angle (°)
D Downward viewing angle (°)
L Leftward viewing angle (°)
R Rightward viewing angle (°)
80+ 80° or more
Chromat Front chromaticity
T Relative transmittance

EXAMPLE 5

(Formation of ellipsoidal polarizing plate)

[0165] An ellipsoidal polarizing plate was prepared in the same manner as in Example 1, except that the second transparent support was not used.

COMPARISON EXAMPLE 3

(Formation of ellipsoidal polarizing plate)

[0166] An ellipsoidal polarizing plate was prepared in the same manner as in Comparison Example 1, except that the second transparent support was not used.

(Optical characteristics of ellipsoidal polarizing plates)

[0167] The optical characteristics of the ellipsoidal polarizing plates prepared in Example 5 and Comparison Example 3 are shown in the following Table 3.

TABLE 3

Sample No.	OA layer		Transparent substrate			
	Re	β	Re	Rth	θ	α
Ex. 5	38	40	0.6	35	45	90
Comp. 3	38	40	0.6	35	0	45

(Remark)
OA: Optically anisotropic
Re: Re retardation value (nm)
Rth: Rth retardation value (nm)
β: Average inclined angle (°) of discotic plane
θ: Angle (°) between the average of directions obtained by projecting normal lines of discotic planes of the discotic compounds on plane of the substrate (rubbing direction) and the slow axis of the transparent substrate (0° means parallel)
α: Angle (°) between the slow axis of the transparent substrate and the transmission axis of the polarizing membrane (90° means perpendicular)

EXAMPLE 6

(Formation of liquid crystal cell of homogeneous alignment mode)

[0168] On a glass plate having an ITO electrode, a polyimide film (orientation layer) was attached, and subjected to a rubbing treatment. The two glass plates were placed by facing the orientation layer with each other. The rubbing direction on one glass plate was antiparallel to the rubbing direction on the other plate. The cell gap was 3.7 μm. A liquid crystal molecule having Δn of 0.0988 (ZLI4792, Merck & Co., Inc.) was injected into the cell gap to prepare a liquid crystal cell of a homogeneous alignment mode.
[0169] The Re retardation value of the liquid crystal cell was measured at the wavelength of 436 nm, 546 nm and 611.5 nm while applying voltage (5 or 5.5 V) of a square wave (55 Hz) to the cell.

(Preparation of liquid crystal display)

[0170] Two ellipsoidal polarizing plates prepared in Example 5 were arranged on both sides of the liquid crystal cell of a bend alignment mode. The optically anisotropic layer of the ellipsoidal polarizing plate was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was antiparallel to the rubbing direction of the orientation layer of the optically anisotropic layer.

COMPARISON EXAMPLE 4

(Preparation of liquid crystal display)

[0171] Two ellipsoidal polarizing plates prepared in Comparison Example 3 were arranged on both sides of the liquid crystal cell of a homogeneous alignment mode prepared in Example 6. The optically anisotropic layer of the ellipsoidal polarizing plate was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was antiparallel to the rubbing direction of the orientation layer of the optically anisotropic layer.

(Evaluation of liquid crystal displays)

[0172] The difference between the Re retardation values of the lamination (the optically anisotropic layer and the first and second transparent substrates) and the liquid crystal cell was calculated. The wavelength dependency was evaluated as the differences measured at the wavelength of 436 nm, 546 nm and 611.5. The results are set forth in Table 4. In Table 4, the wavelength dependency is shown as a relative value based on the result measured at the wavelength of 546 nm as the standard value (0).
[0173] Voltage (55 Hz) of a square wave was applied to the liquid crystal cell of the liquid crystal displays prepared in Example 6 and Comparison Example 4. An image was displayed according to a normally white mode (white: 2V, black: 5V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured. The viewing angle was evaluated as an angle that can view an image

having a contrast ratio of not smaller than 10.

[0174] Further, the front chromaticity of the black image was measured.

[0175] Furthermore, the transmittance of the liquid crystal display was measured at the wavelength of 436 nm. The result was evaluated as a relative value based on the transmittance of a lamination of two polarizing membranes (para nicols arrangement) measured at the wavelength of 436 nm as the standard value (100%).

TABLE 4

Sample	Dependency			Viewing angle				Chromat.		T
	436	546	611.5	U	D	L	R	x	y	(%)
Ex.6	8.1	0	-2.6	75	45	56	55	0.203	0.053	0.33
C4	18.1	0	-8.2	76	45	55	55	0.246	0.082	1.66

(Remark)
C: Comparison Example
U: Upward viewing angle (°)
D: Downward viewing angle (°)
L: Leftward viewing angle (°)
R: Rightward viewing angle (°)
Chromat.: Front chromaticity
T: Relative transmittance

Claims

1. A liquid crystal display comprising a liquid crystal cell of a bend alignment mode and two polarizing elements, each of which is arranged on each side of the liquid crystal cell, at least one of said polarizing elements being an ellipsoidal polarizing plate comprising a lamination of an optically anisotropic layer, a transparent substrate and a polarizing membrane, said optically anisotropic layer containing discotic compounds, said transparent substrate boing optically anisotropic, and said polarizing mombrano boing arranged as an outormost layor of tho liquid crystal display,

   wherein the optically anisotropic layer and the transparent substrate are so arranged that an angle between a normal discotic direction and a slow axis in plane of the transparent substrate is essentially 45°, said normal discotic direction being an average of directions obtained by projecting normal lines of discotic planes of the discotic compounds on plane of the substrate, and wherein the transparent substrate and the polarizing membrane are so arranged that a slow axis in plane of the transparent substrate is essentially parallel to or essentially perpendicular to a transmission axis in plane of the polarizing membrane.

2. The liquid crystal display as defined in claim 1, wherein the transparent substrate has a Re retardation value defined by the formula (1) in the range of 5 to 100 nm and a Rth retardation value defined by the formula (2) in the range of 100 to 1,000 nm:

   $$(1) \qquad Re - (nx\text{-}ny)\times d$$

   $$(2) \qquad Rth = [(nx+ny)/2\text{-}nz\}\times d$$

   in which nx is a refractive index of a slow axis in plane of the transparent substrate, ny is a refractive index of a fast axis in plane of the transparent substrate, nz is a refractive index of a thickness direction of the transparent substrate, and d is a thickness of the transparent substrate.

3. The liquid crystal display as defined in claim 1, wherein the ellipsoidal polarizing plate comprises an optically anisotropic layer, a transparent substrate and a polarizing membrane in this order.

4. The liquid crystal display as defined in claim 1, wherein the ellipsoidal polarizing plate comprises a lamination of two or more optically anisotropic transparent substratos, and at least one of the substratos, the optically anisotropic layer and the polarizing membrane are arranged as defined above.

5. The liquid crystal display as defined in claim 4, wherein one transparent substrate is a cellulose ester film, another transparent substrate is a polycarbonate film, and the ellipsoidal polarizing plate comprises an optically anisotropic layer, a cellulose ester film, a polycarbonate film and a polarizing membrane in this order.

6. The liquid crystal display as defined in claim 1. wherein the ellipsoidal polarizing plate comprises a lamination of two or more optically anisotropic transparent substrates, and each of the substrates, the optically anisotropic layer and the polarizing membrane are arranged as defined above.

7. The liquid crystal display as defined in claim 6, wherein one transparent substrate is a cellulose ester film, another transparent substrate is a polycarbonate film, and the ellipsoidal polarizing plate comprises an optically anisotropic layer, a cellulose ester film, a polycarbonate film and a polarizing membrane in this order.

8. The liquid crystal display as defined in claim 6, wherein the lamination of the transparent substrates has a Re retardation value defined by the formula (1) in the range of 5 to 100 nm and a Rth retardation value defined by the formula (2) in the range of 100 to 1,000 nm:

$$(1) \qquad Re = (nx\text{-}ny) \times d$$

$$(2) \qquad Rth = [(nx+ny)/2\text{-}nz] \times d$$

in which nx is a refractive index of a slow axis in plane of the lamination of the transparent substrates, ny is a refractive index of a fast axis in plane of the lamination of the transparent substrates, nz is a refractive index of a thickness direction of the lamination of the transparent substrates, and d is a thickness of the lamination of the transparent substrates.

9. The liquid crystal display as defined in claim 8, wherein the ellipsoidal polarizing plate comprises an optically anisotropic layer a lamination of transparent substrates and a polarizing membrane in this order, and the transparent substrate facing the polarizing membrane and the polarizing membrane are so arranged that a slow axis in plane of the transparent substrate is essentially parallel to a transmission axis in plane of the polarizing membrane

10. The liquid crystal display as defined in claim 1, wherein each of the polarizing elements is an ellipsoidal polarizing plate comprising a lamination of an optically anisotropic layer, a transparent substrate and a polarizing membrane, said optically anisotropic layer containing discotic compounds, said transparent substrate being optically anisotropic and wherein the transparent substrate, the optically anisotropic layer and the polarizing membrane are arranged as defined above in each of the ellipsoidal polarizing plates.

11. A liquid crystal display comprising a liquid crystal cell of a homogeneous alignment mode and two polarizing elements each of which is arranged on each side of the liquid crystal cell, at least one of said polarizing elements being an ellipsoidal polarizing plate comprising a lamination of an optically anisotropic layer, a transparent substrate and a polarizing membrane, said optically anisotropic layer containing discotic compounds, said transparent substrate being optically anisotropic, and said polarizing membrane being arranged as an outermost layer of the liquid crystal display

wherein the optically anisotropic layer and the transparent substrate are so arranged that an angle between a normal discotic direction and a slow axis in plane of the transparent substrate is essentially 45°, said normal discotic direction being an average of directions obtained by projecting normal lines of discotic planes of the discotic compounds on plane of the substrate, and wherein the transparent substrate and the polarizing membrane are so arranged that a slow axis in plane of the transparent substrate is essentially parallel to or essentially perpendicular to a transmission axis in plane of the polarizing membrane.

12. The liquid crystal display as defined in claim 11, wherein the transparent substrate has a Re retardation value defined by the formula (1) in the range of 0 to 100 nm and a Rth retardation value defined by the formula (2) in the range of 10 to 1,000 nm:

$$(1) \qquad Re = (nx\text{-}ny) \times d$$

$$(2) \qquad Rth = [(nx+ny)/2-nz]\times d$$

in which nx is a refractive index of a slow axis in plane of the transparent substrate, ny is a refractive index of a fast axis in plane of the transparent substrate, nz is a refractive index of a thickness direction of the transparent substrate, and d is a thickness of the transparent substrate.

13. The liquid crystal display as defined in claim 11, wherein the ellipsoidal polarizing plate comprises an optically anisotropic layer, a transparent substrate and a polarizing membrane in this order.

14. The liquid crystal display as defined in claim 11, wherein each of the polarizing elements is an ellipsoidal polarizing plate comprising a lamination of an optically anisotropic layer, a transparent substrate and a polarizing membrane, said optically anisotropic layer containing discotic compounds, said transparent substrate being optically anisotropic, and wherein the transparent substrate, the optically anisotropic layer and the polarizing membrane are arranged as defined above in each of the ellipsoidal polarizing plates.

15. An ellipsoidal polarizing plate comprising a lamination of an optically anisotropic layer, a transparent substrate and a polarizing membrane, said optically anisotropic layer containing discotic compounds, said transparent substrate being optically anisotropic, and said polarizing membrane being arranged as an outermost layer,

wherein the optically anisotropic layer and the transparent substrate are so arranged that an angle between a normal discotic direction and a slow axis in plane of the transparent substrate is essentially 45°, said normal discotic direction being an average of directions obtained by projecting normal lines of discotic planes of the discotic compounds on plane of the substrate, and wherein the transparent substrate and the polarizing membrane are so arranged that a slow axis in plane of the transparent substrate is essentially parallel to or essentially perpendicular to a transmission axis in plane of the polarizing membrane.

16. The ellipsoidal polarizing plate as defined in claim 15, wherein the transparent substrate has a Re retardation value defined by the formula (1) in the range of 0 to 100 nm and a Rth retardation value defined by the formula (2) in the range of 10 to 1,000 nm:

$$(1) \qquad Re = (nx-ny)\times d$$

$$(2) \qquad Rth = [(nx+ny)/2-nz]\times d$$

in which nx is a refractive index of a slow axis in plane of the transparent substrate, ny is a refractive index of a fast axis in plane of the transparent substrate, nz is a refractive index of a thickness direction of the transparent substrate, and d is a thickness of the transparent substrate.

17. The ellipsoidal polarizing plate as defined in claim 15, wherein the ellipsoidal polarizing plate comprises an optically anisotropic layer, a transparent substrate and a polarizing membrane in this order.

18. The ellipsoidal polarizing plate as defined in claim 15, wherein the ellipsoidal polarizing plate comprises a lamination of two or more optically anisotropic transparent substrates, and at least one of the substrates, the optically anisotropic layer and the polarizing membrane are arranged as defined above.

19. The ellipsoidal polarizing plate as defined in claim 18, wherein one transparent substrate is a cellulose ester film, another transparent substrate is a polycarbonate film, and the ellipsoidal polarizing plate comprises an optically anisotropic layer, a cellulose ester film, a polycarbonate film and a polarizing membrane in this order.

20. The ellipsoidal polarizing plate as defined in claim 16, wherein the ellipsoidal polarizing plate comprises a lamination of two or more optically anisotropic transparent substrates, and each of the substrates, the optically anisotropic layer and the polarizing membrane are arranged as defined above.

21. The ellipsoidal polarizing plate as defined in claim 20, wherein one transparent substrate is a cellulose ester film, another transparent substrate is a polycarbonate film, and the ellipsoidal polarizing plate comprises an optically anisotropic layer, a cellulose ester film, a polycarbonate film and a polarizing membrane in this order.

22. The ellipsoidal polarizing plate as defined in claim 20, wherein the lamination of the transparent substrates has a Re retardation value defined by the formula (1) in the range of 5 to 100 nm and a Rth retardation value defined by the formula (2) in the range of 100 to 1,000 nm:

$$(1) \qquad Re = (nx-ny)\times d$$

$$(2) \qquad Rth = [(nx+ny)/2-nz]\times d$$

in which nx is a refractive index of a slow axis in plane of the lamination of the transparent substrates, ny is a refractive index of a fast axis in plane of the lamination of the transparent substrates, nz is a refractive index of a thickness direction of the lamination of the transparent substrates, and d is a thickness of the lamination of the transparent substrates.

23. The ellipsoidal polarizing plate as defined in claim 22, wherein the ellipsoidal polarizing plate comprises an optically anisotropic layer, a lamination of transparent substrates and a polarizing membrane in this order, and the transparent substrate facing the polarizing membrane and the polarizing membrane are so arranged that a slow axis in plane of the transparent substrate is essentially parallel to a transmission axis in plane of the polarizing membrane.

Fig. 1

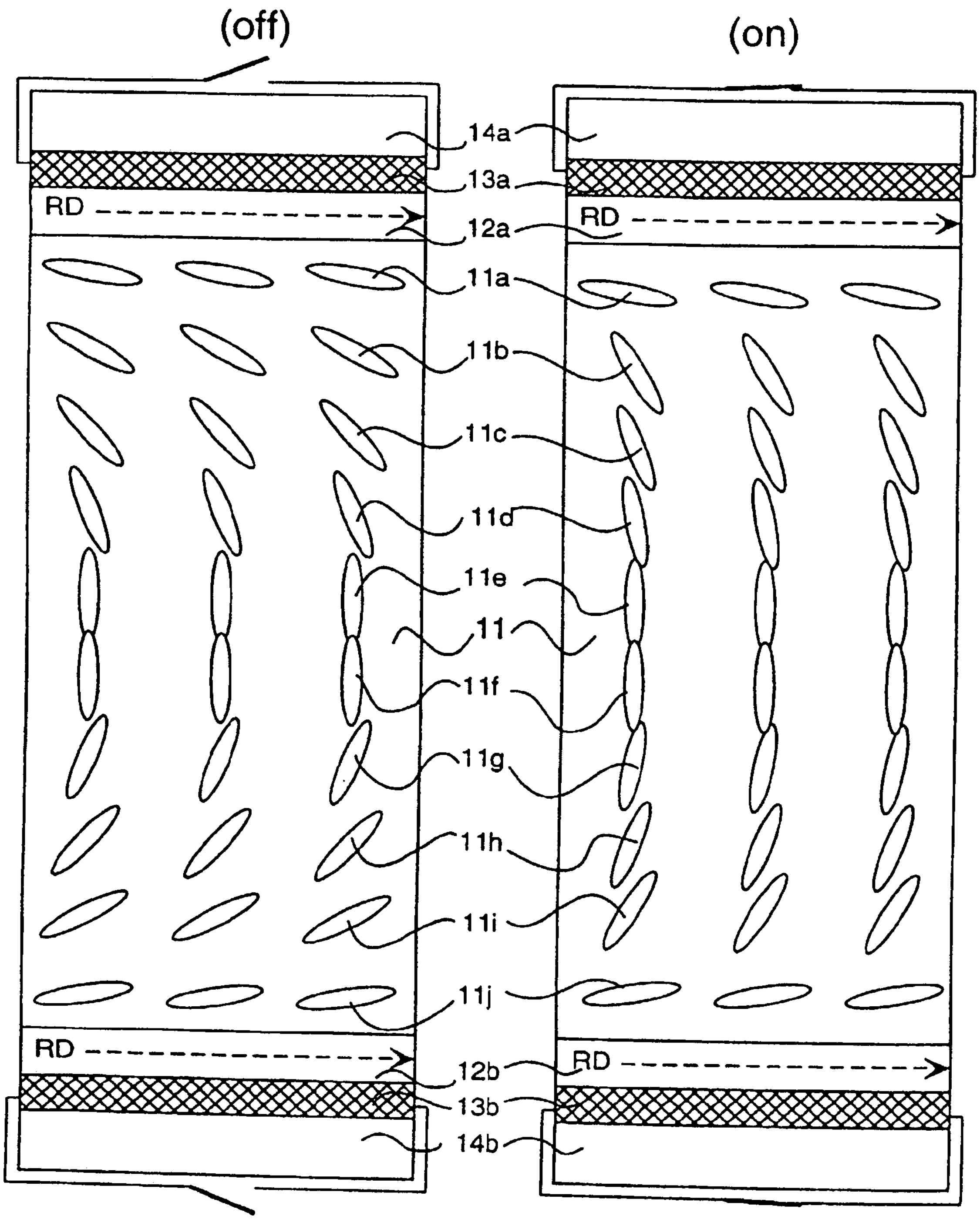

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Fig. 2

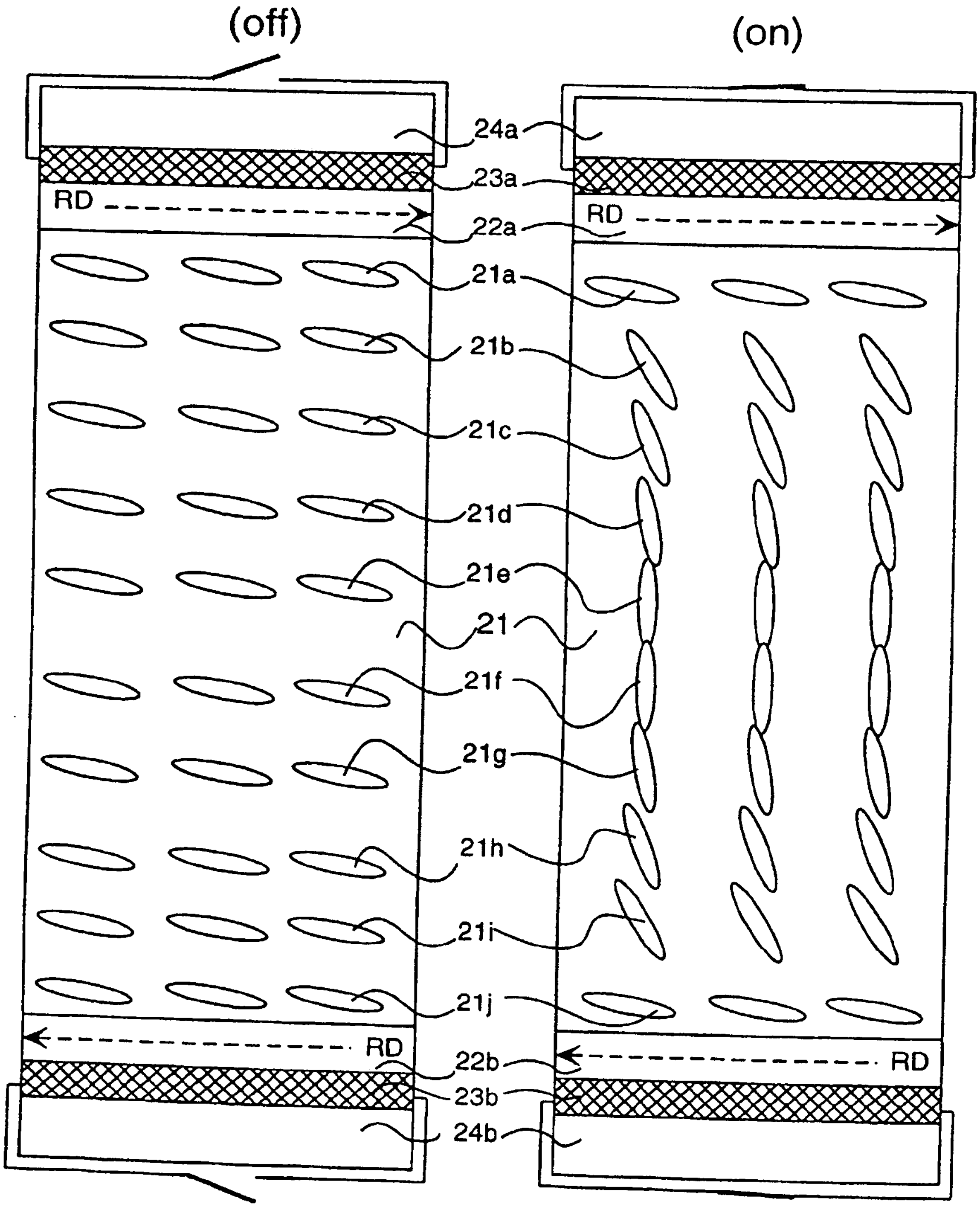
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Fig. 3

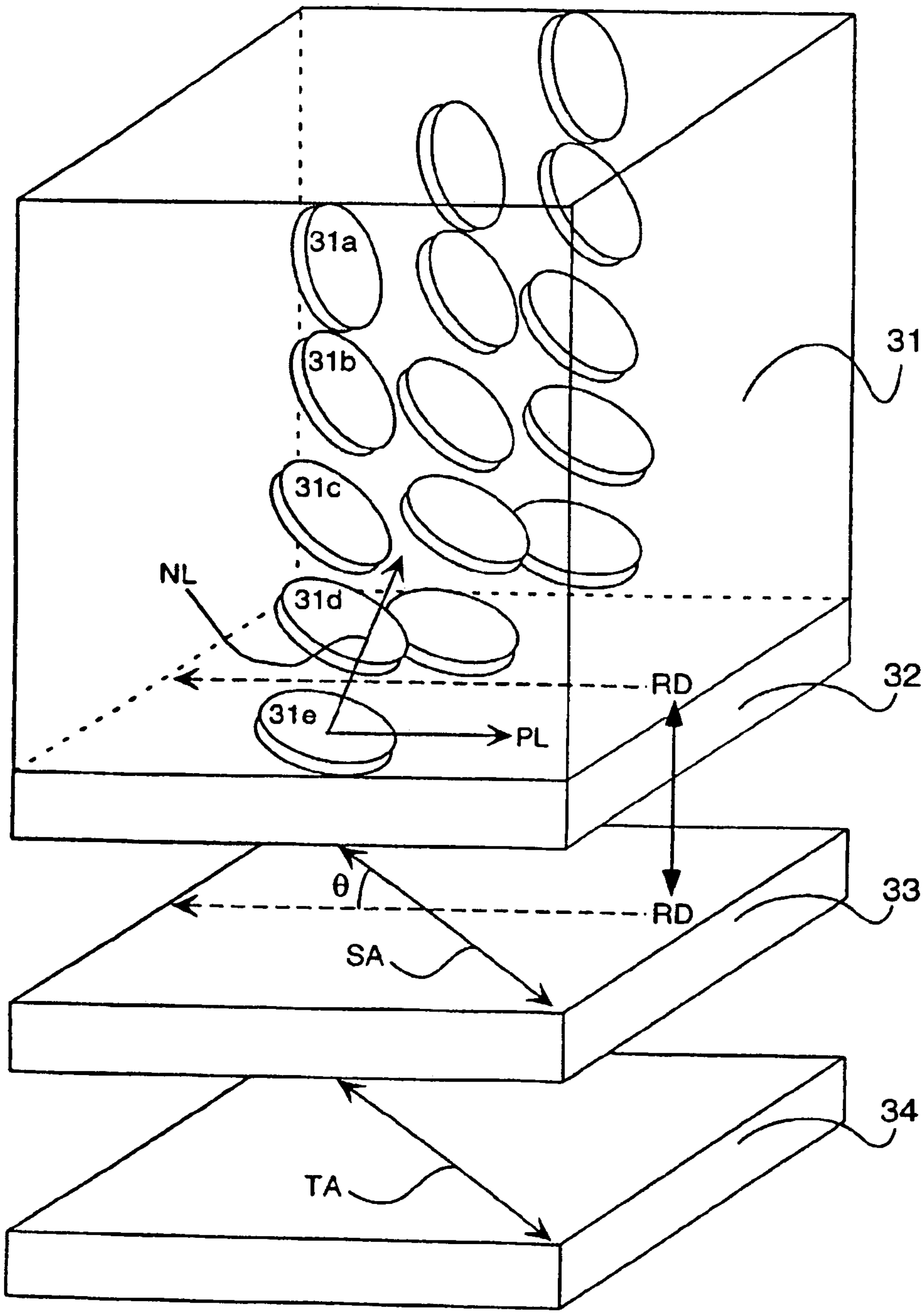

Fig. 4

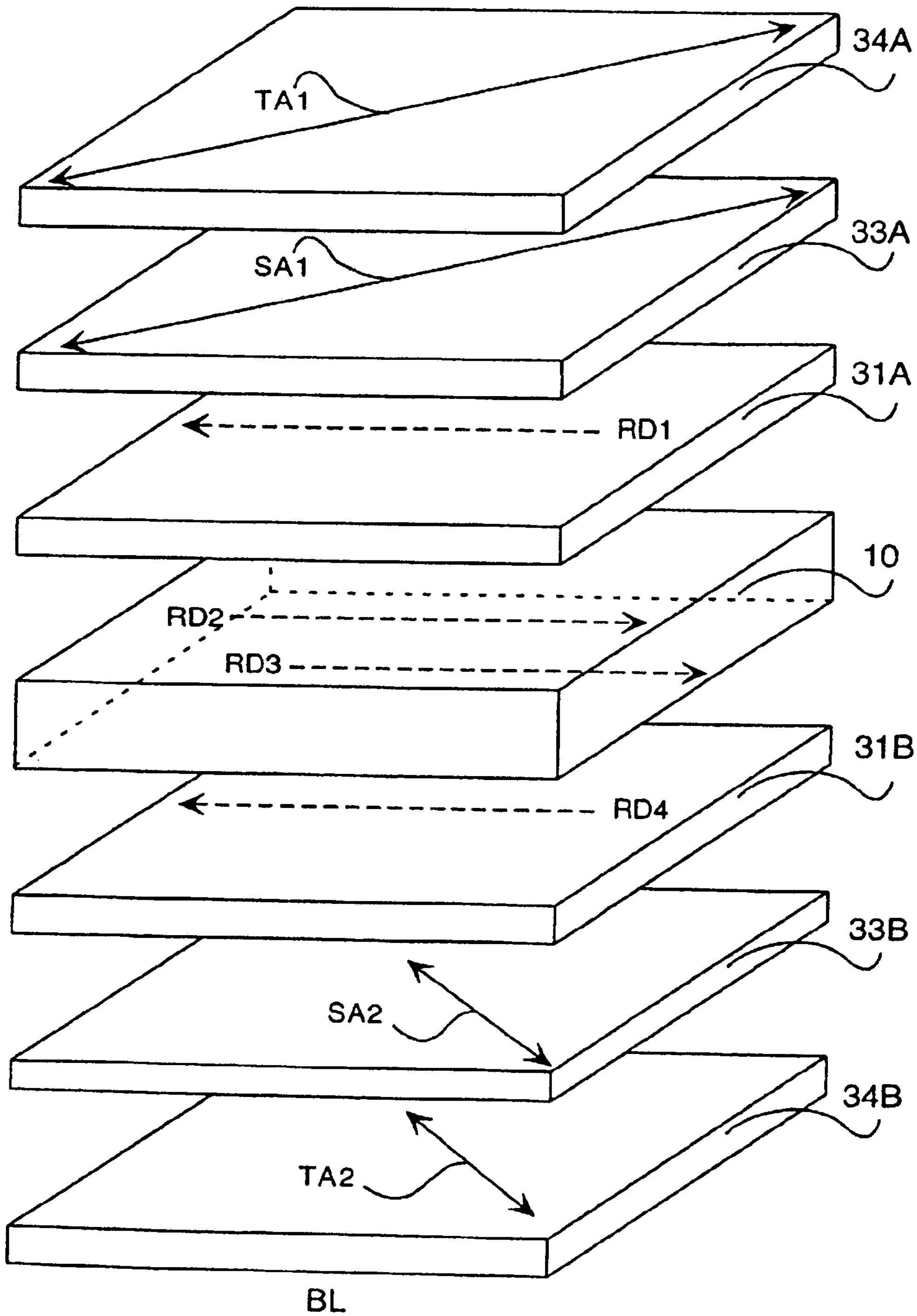

Fig. 5

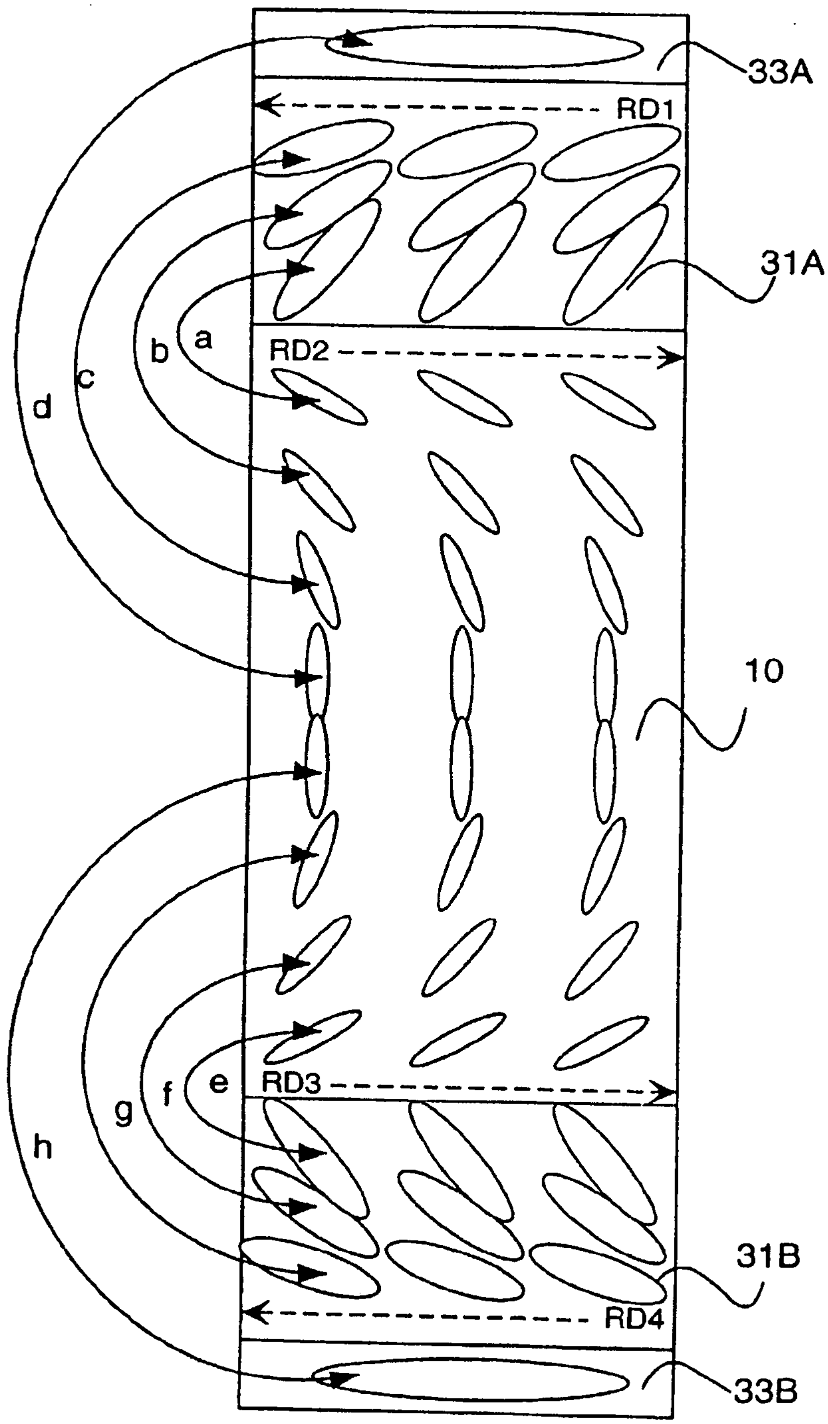

Fig. 6

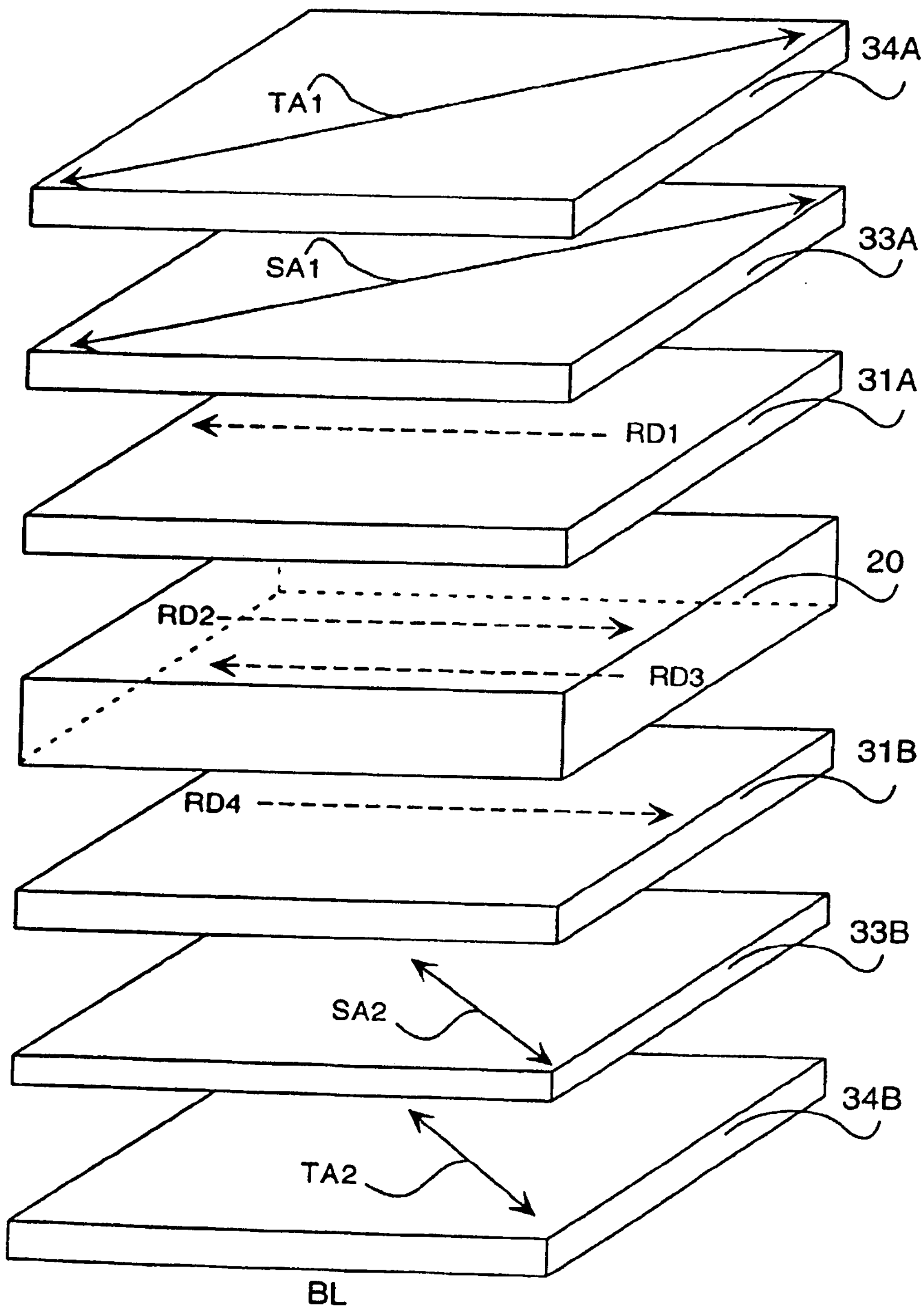

Fig. 7

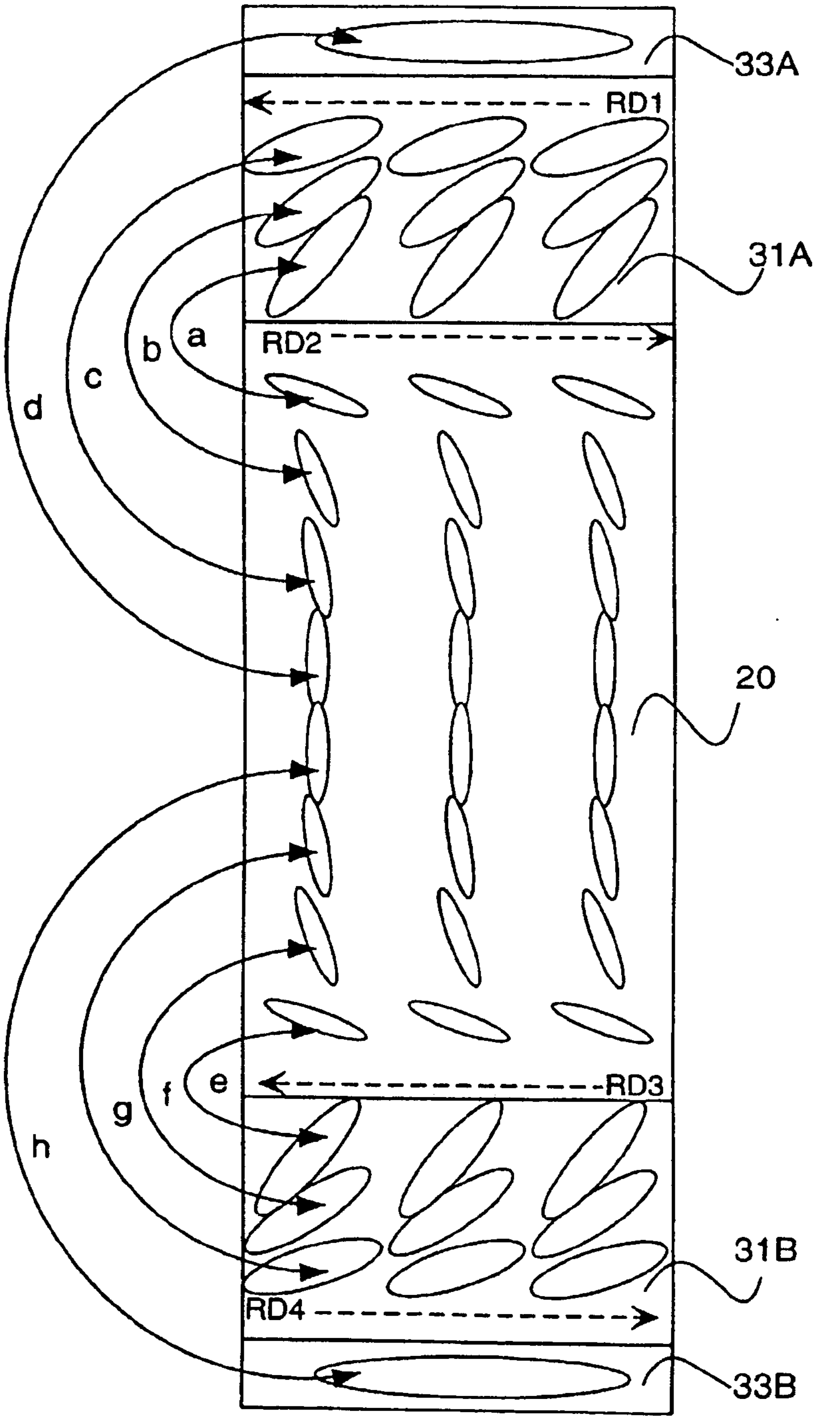

Fig. 8

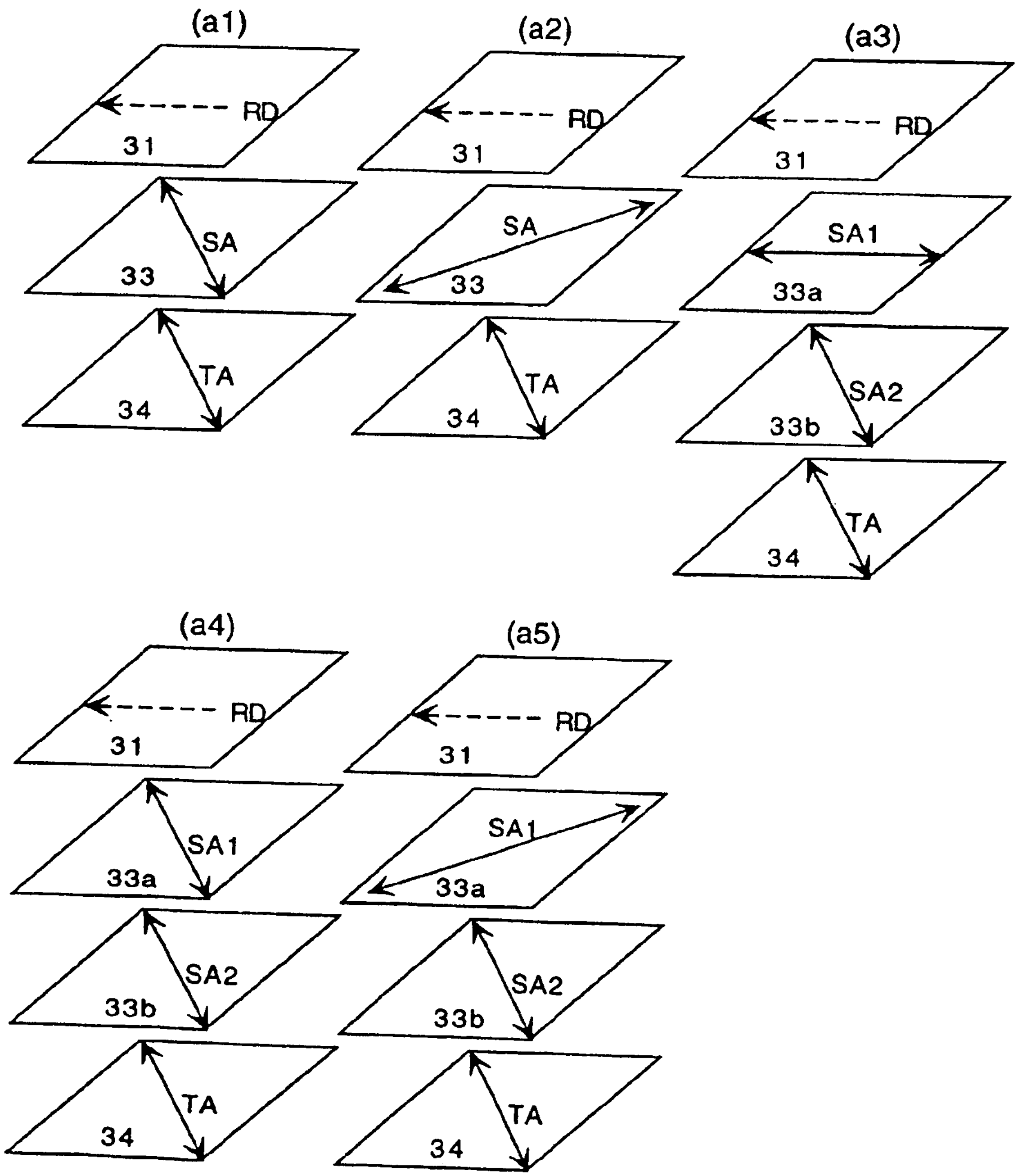
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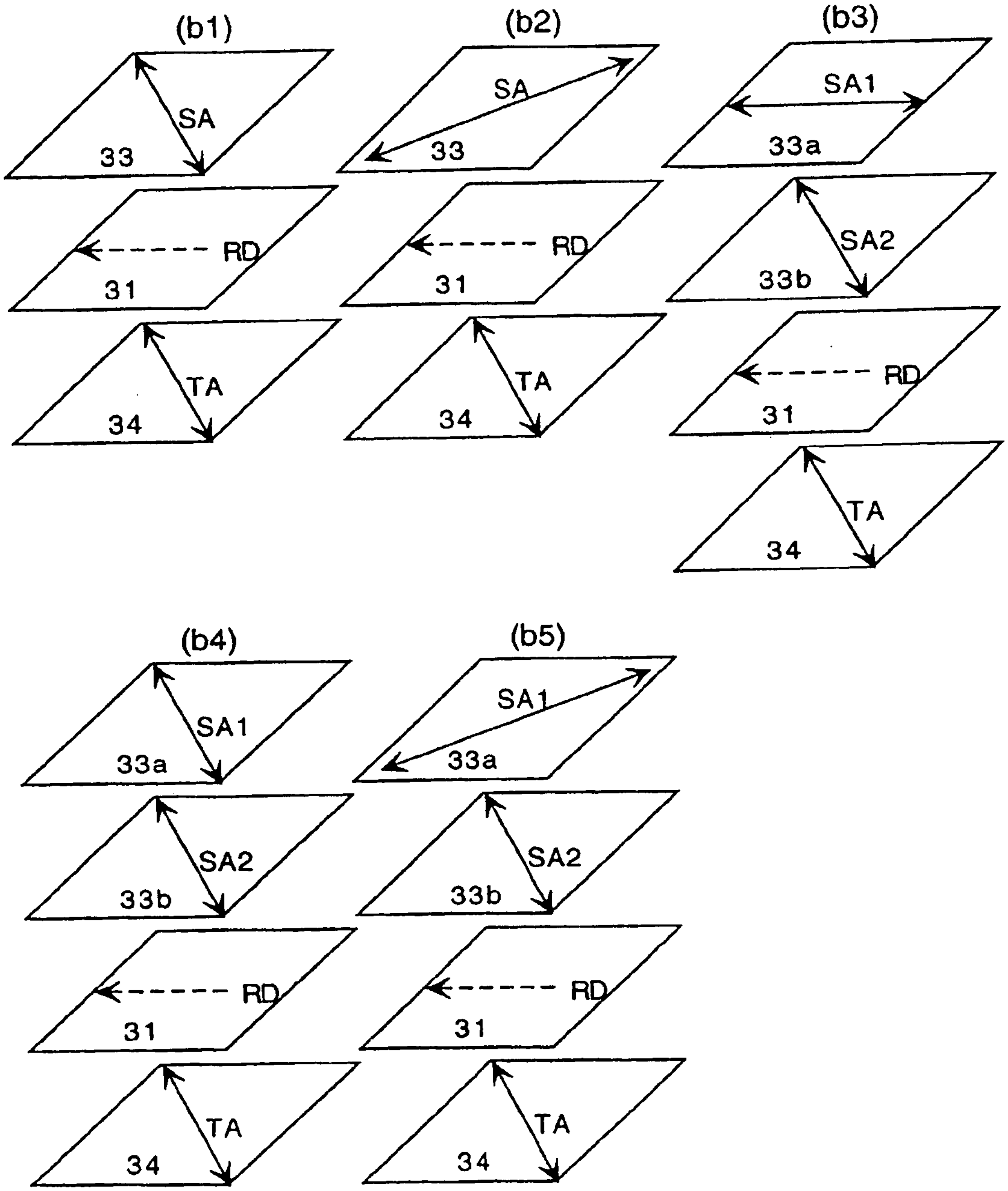
Fig. 9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33a
SA2
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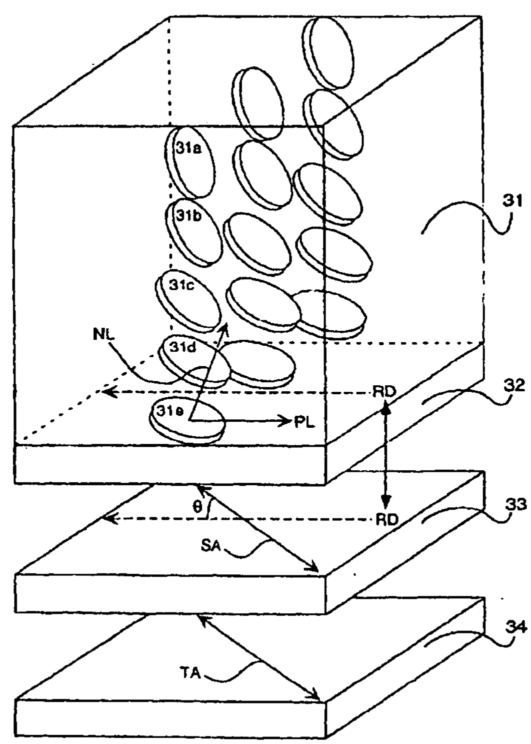
(54) Optical compensating sheet and liquid crystal display comprising the sheet

(57) A liquid crystal display comprises a liquid crystal cell of a bend alignment mode or a homogeneous alignment mode and two polarizing elements. Each of the elements is arranged on each side of the liquid crystal cell. At least one of the polarizing elements is an ellipsoidal polarizing plate. The ellipsoidal polarizing plate comprises a lamination of an optically anisotropic layer (31), a transparent substrate (33) and a polarizing membrane (34). The optically anisotropic layer contains discotic compounds (31a,...,31e). The transparent substrate is optically anisotropic. The polarizing membrane is arranged as an outermost layer of the liquid crystal display. The optically anisotropic layer and the transparent substrate are so arranged that an angle between a normal discotic direction and a slow axis (SA) in plane of the transparent substrate is essentially 45°. The normal discotic direction is an average of directions obtained by projecting normal lines (NL) of discotic planes of the discotic compounds on the plane of the substrate. The transparent substrate and the polarizing membrane are so arranged that the slow axis (SA) in plane of the transparent substrate is essentially parallel to or essentially perpendicular to the transmission axis (TA) of the polarizing membrane.

Fig. 3



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EUROPEAN SEARCH REPORT

Application Number
EP 98 12 4703

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 726 486 A (FUJI PHOTO FILM CO LTD) 14 August 1996 * page 6, line 52 - page 7, line 12 * * page 43, line 51 - page 44, line 36; figures 3,4 *	1-23	G02F1/1335
A	EP 0 774 683 A (FUJI PHOTO FILM CO LTD) 21 May 1997 * page 8, line 17 - page 8, line 48 * * page 17, line 24 - page 21, line 49; figures 8,9 *	1-23	
A	US 5 528 400 A (FUJI PHOTO FILM CO LTD) 18 June 1996 * column 4, line 56 - column 8, line 67; figure 5 *	1-23	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
G02F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	28 April 1999	Lerbinger, K

CATEGORY OF CITED DOCUMENTS

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28-04-1999

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EPO FORM P0459

For more details about this annex see Official Journal of the European Patent Office, No. 12/82

33.3: Development of Super-High-Image-Quality Vertical-Alignment-Mode LCD

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p845–848 = (4)

Abstract

We have developed a vertically aligned LCD (VA-LCD) which offers the same image quality of a CRT. This display has a super-wide viewing angle of over 70° in all directions, a fast response (< 25 ms), and a high contrast ratio of over 300. The VA-LCD has been successfully implemented by optimizing a vertically aligned mode with a domain-divided structure and an optical compensator. We describe the optimization of a panel parameter and an optical compensator by computer simulation, and show the experimental results. We realized a 10.4-inch-diagonal VGA full-color prototype VA-LCD with super high quality.

1. Introduction

Currently, the market for LCDs is increasing rapidly. However, the viewing angle and contrast ratio of LCDs are still insufficient for their use in large-screen products. For high image quality, these characteristics need to be improved.

Recently, many methods for wide viewing angle TFT-addressed LCDs have been proposed. These methods use DDTN mode,[1] IPS mode,[2] as well as other optically compensated modes : OCB,[3] Compensator Film,[4] and D-HAN.[5] We had already realized a DDTN-LCD in 1992.[6] To further improve the viewing angle, we adopted VA mode for a high quality LCD [7] which has a pure black image at the off state. The VA mode itself is very old. Recent improvements in materials which include the liquid crystal and alignment layers, have made application of this mode possible in TFT-LCDs.

First of all, the optimization of the panel parameter and optical compensator condition in the VA mode was examined by simulation. Then the simulation results and the characteristics of VA test cells were compared, including the reasons for a wide viewing angle, a high-speed response, and a high contrast ratio. Finally, the high image quality was proved using a 10.4-inch-diagonal VGA full-color prototype VA-LCD.

2. Simulation

Figure 1 shows the panel structure of the adopted VA mode. In this panel structure, the viewing angle and the transmittance when Δnd ($\Delta n = ne - no$, d are cell gap) is changed are shown in Figure 2. We found that the viewing angle increases as Δnd decreases, and that the transmittance decreases to less than $\Delta nd = 0.3\ \mu m$. The method of adding a negative retardation film equal to Δnd to improve the viewing angle has been reported.[8] However, in this method, the viewing angle

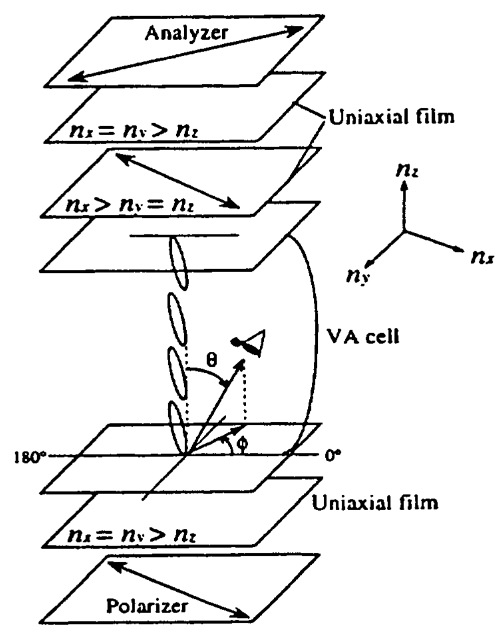

Figure 1. Panel structure of adopted VA-LCD.

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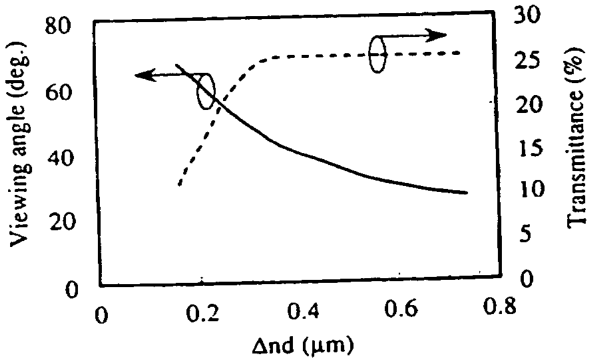


Figure 2. Dependence of viewing angle and transmittance on Δnd.

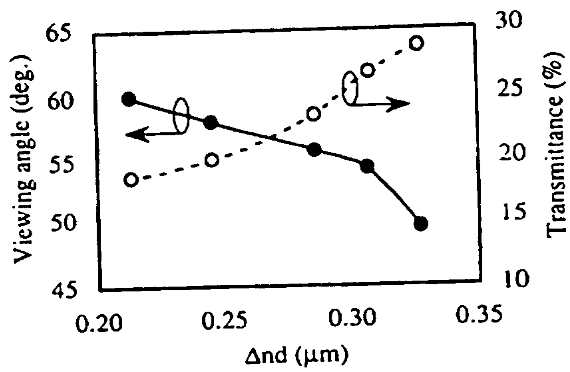


Figure 4. Dependence of viewing angle and transmittance on Δnd.

improvement is not enough.

Therefore, we added a uniaxial positive retardation film on a uniaxial negative retardation film. This optical compensation method decreases the transmittance of the off state in the azimuth of $\phi = 0°$ which is angled at $\phi = 45°$ to the polarizer or analyzer absorption axis. Figure 3 shows the transmittance characteristics of the off state when a negative and a positive retardation film are added. The transmittance at $\phi = 90°$ decreases, mostly when the positive retardation is about 50 nm.

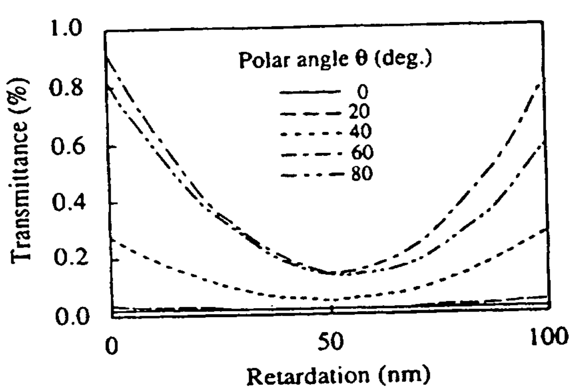


Figure 3. Dependence of retardation of a positive compensator.

3. Results and Discussion

3.1 Viewing angle characteristics

The VA panel uses a vertical alignment layer and a dielectrically negative LC mixture. The fabrication process of the VA cell is the same as for a conventional TN cell. Figure 4 shows the optical characteristics of the VA cell when Δnd is changed. It is clear that as the cell gap decreases, the viewing angle increases according to the decrease in transmittance. This almost corresponds the simulated results shown in Figure 2. Figure 5 shows the viewing angle characteristics of the VA cell (Δnd=0.25 μm) and a conventional TN cell. We found that the viewing angle (C.R. > 10) of the VA cell is much wider than for a conventional TN cell. In particular, the vertical characteristics are much better than a conventional TN cell.

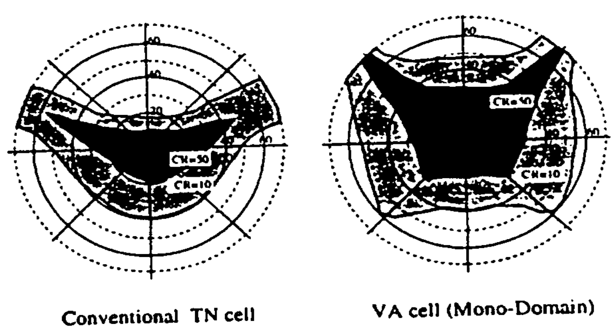


Figure 5. Viewing angles of a conventional TN cell and aVA cell.

Figure 6 shows that the viewing angle characteristics of the VA panel using an optical compensator are improved greatly. In addition, we adopted a domain-dividing structure for the VA cell and succeeded to improve the viewing angle characteristics in all directions. Figure 7 shows the viewing angle of a domain-divided VA cell. We have achieved a super-wide viewing angle (>70°) in all directions.

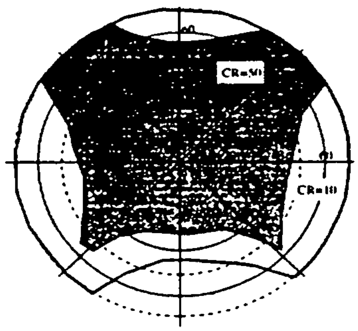


Figure 6. Viewing angles of a compensated VA cell.

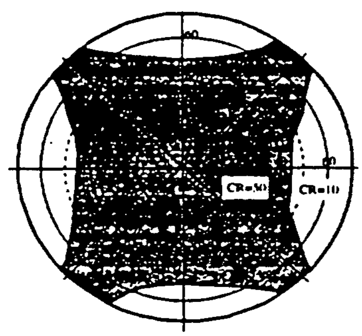


Figure 7. Viewing angles of a domain-divided VA cell.

3.2 Response characteristics

The experimental results showed that the response speed of the VA cell is higher in proportion to the decrease in the cell gap. However, if we adopt a domain-dividing structure, the response speed will depend largely on the domain-divided pattern (Table 1). We can obtain the highest response speed by adopting a domain-divided pattern (a).

3.3 High contrast ratio

Basically, the contrast ratios of TN mode and of VA mode are expected to be the same. However, it is different in a real cell. Figure 8 shows the difference in the light-leakage of the vertically aligned cell (VA cell) and the homogeneous aligned cell (HA cell) with crossed polarizers. In VA mode, we found that there is very little light-leakage around the spacers compared with that in homogeneous aligned mode. Because there is less distortion of the liquid crystal molecules around the spacers in VA mode than in homogeneous aligned mode, the VA cell has a higher contrast ratio.

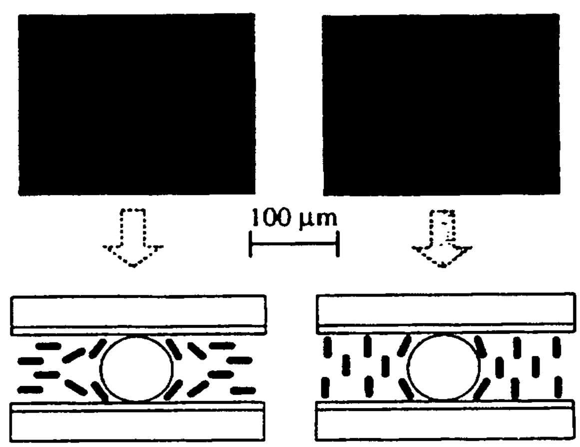
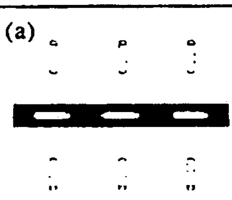
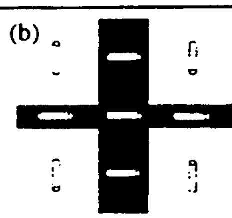
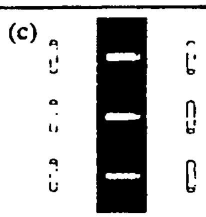


Figure 8. Light-leakage around spacers.

Table1. Response characteristics of domain divided VA-cells.

	(a)	(b)	(c)
Domain pattern			
Ton (ms)	8	42	209
Toff (ms)	5	5	5

4. 10.4-Inch Prototype VA-LCD

The VA-LCD panel was fabricated using a conventional TFT substrate (10.4-inch VGA) and a CF substrate. The viewing angle characteristics of this panel are shown in Figures 9 and 10. It is obvious that the VA-LCD has very wide viewing angle characteristics with no gray-scale inversion. Table 2 shows the specifications of a 10.4-inch VA-LCD. It is clear that the VA-LCD has super-wide viewing angle characteristics, a high-speed response, and high contrast ratio.

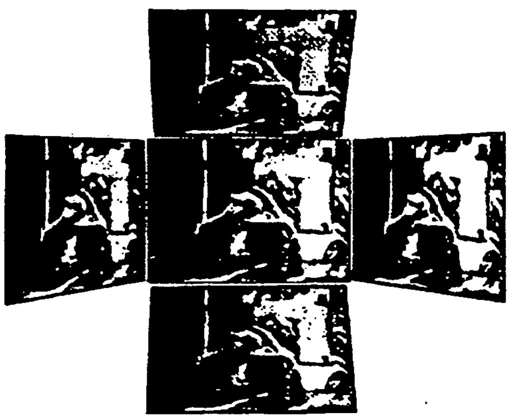
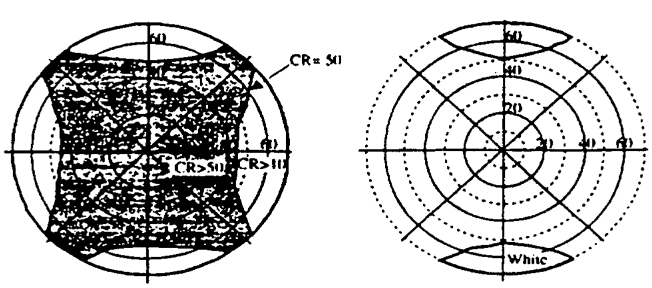


Figure 9. Display characteristics of a VA LCD.

This figure is reproduced in color on page 1135.

Table 2. Specifications of 10.4-inch VA-LCD.

Display area	10.4-inch-diagonal
Viewing angle (CR>10)	> 70° all directions
Contrast ratio	> 300
Response time	< 25 ms
Driving voltage	5 V



Iso-contrast Inversion (8 Levels)

Figure 10. Viewing angle characteristics of aVA-LCD.

5. Conclusion

We have developed a large-area, high-image quality LCD which is almost equal to a CRT, by combining the domain-dividing technique with the optimized vertical alignment mode. We believe that this large-area panel can be used as a replacement for the CRT and the technology we have developed will become important for future large-area LCDs.

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P. 315-318 (4)

XP-002284819

21.2: Optimum Film Compensation Modes for TN and VA LCDs

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Abstract

The compensation principle to reduce the off-axis light leakage of crossed polarizers is investigated. After optimizing the retardation films, the simulation results show that the black state of viewing angle of compensated TN and VA modes can be made wider than the angle of view of crossed polarizers. The results are also confirmed by the test cells.

I. Introduction

It is well known that the conventional TN LCDs have inherent narrow and non-uniform viewing angle characteristics, which results from the LC material is highly optical anisotropic. It has been demonstrated that the optical film compensation is a very effective way to fix this problem[1-6]. As a consequence, various compensation films have been designed and manufactured. They are now commercially available and have become an indispensable optical component for various LC modes. For the normal TN modes, a powerful compensation film was developed by Fuji Photo Film [4], which has a negative birefringence discotic layer with a splayed structure. The similar LC director profile of discotic layer in Fuji film to that of TN on state results in the nice compensation effect. For the vertically aligned mode, negative c-plate films are usually used to reduce the light leakage at the 45^0 viewing planes relative to polarizers [6]. In the last year SID conference, Fujitsu Co released using a-c-plate combination compensation mode for VA LCDs [5]. However, its principle of compensation mode was not explained.

In this paper, we focus on the compensation modes to reduce the off-axis light leakage from crossed polarizers. The principle is revealed by the Poincare sphere technique. Several new compensation modes for TN and VA LCDs are developed by using this principle. After optimizing the retardation films, the black state viewing angle of compensated TN and VA modes can be made wider than that of crossed polarizers. The measurements from test cells and real LCD panels fully support the simulation results.

II. Reduction of the off-axis light leakage through crossed polarizers by retardation films

Assuming there is a pair of crossed polarizers in xy plane whose transmission axes are oriented at 45^0 and 135^0 respectively. The angle between transmission axes changes to two times of arctg(cosθ) if the viewing direction is in the bisect planes of two transmission axes with a polar angle θ. They are not orthogonal to each other. Therefore, the light leakage is inevitable if θ is not equal to zero.

In order to eliminate the light leakage, the final polarization state must exit at **B**, which is opposite to transmission axis of analyzer **A** as illustrated by the Poincare sphere in Fig.1 (a) (projecting to the equator plane of Poincare sphere). In order to keep the head-on transmission unchanged, the simplest compensation mode is to use combination of a- and c-plate compensation films or biaxial film. The optical axis of a-plate has to be aligned along to the transmission axis of its adjacent polarizers. The c-plate is arranged such that its optical axis normal to the sample. For the biaxial film, it optical axes should also match with the transmission axis of polarizer. The principle of using a- and c-plate compensation mode is illustrated in Fig.1(b). First, the c-plate (optics axis along y axis) tips up the polarization state from **P** to **B'** then a-plate, whose optical axis passes through **P** and **O**, rotates it onto the equator **B** (the black point). Obviously if the retardation values of a and c-plate are properly selected, we can convert the polarization state **P**

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to **B** and the exit light is totally blocked by the analyzer.

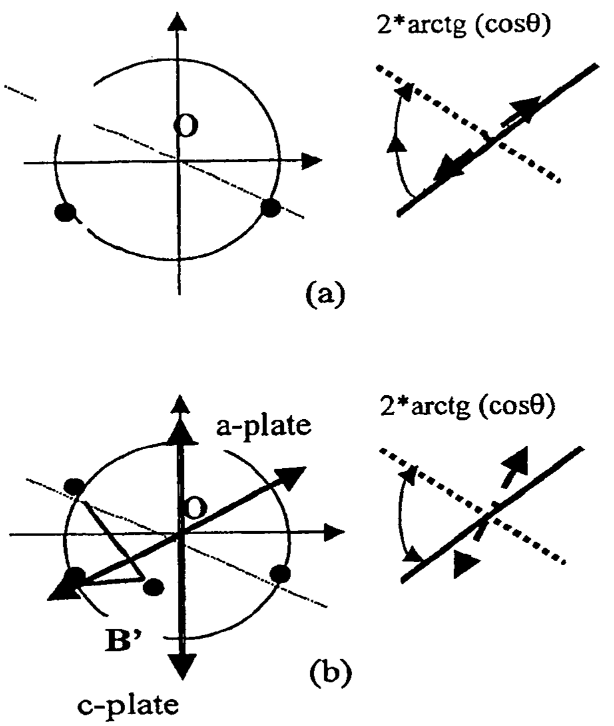

Fig.1 (a) Transmission axes of crossed polarizers represented in Poincare sphere(viewing from north pole). The viewing direction is in the bisect planes of crossed polarizers with a polar angle θ.
(b) The effect of c- and a-plate retarders on the polarization of light. The polarization of the exit light can finally reach the equator and be opposite to the analyzer state. The arrow in the figure of right side indicates the polarization state before light hits the analyzer.

Let us look at a typical example. Fig.2(a) shows the viewing angle characteristic of a pair of crossed polarizers without compensation. Fig.2 (b) shows the viewing angle characteristic of a pair of crossed polarizers with a-plate (100nm) and c-plate (130nm) compensation films. The optical axis of a-plate matches its adjacent polarizer's transmission axis. The intrinsic light leakage is dramatically reduced in the compensation mode. In our calculation, polarizer possessing −40nm retardation has been considered and the spectra white light source is used.

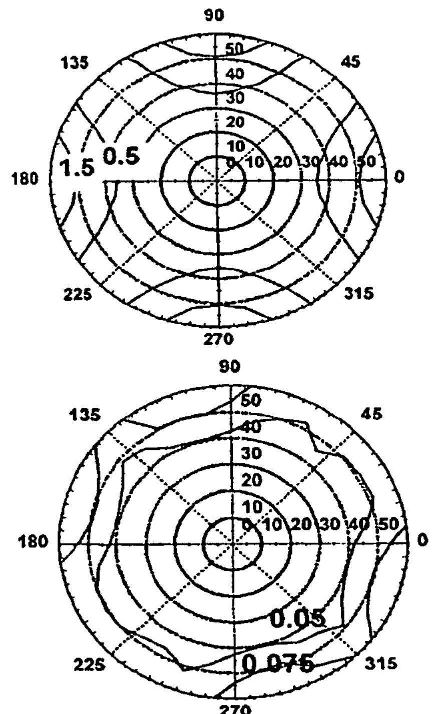

Fig.2 (a) The light transmission through crossed polarizer without film compensation. (b) The light transmission through crossed polarizer with c-plate (130nm) and a-plate (100nm) compensation. Polarizer retardation (-40nm) is considered during calculation.

After detailed simulation, we found the following rules for compensation optimization:
1) Combination of a-plate and c-plate or single biaxial retardation film can be used to eliminate the intrinsic off-axis light leakage of crossed polarizers.
2) The optical axis of a-plate and the axis of biaxial film should align along the transmission axis of their adjacent polarizer.
3)The optimum value of c-plate is about ±80nm in order for a-plate to convert the polarization state from **P** to **B**. The retardation value of a-plate is around ±137nm(1/4λ plate) or (-+) 400nm(3/4λ plate) corresponding to positive and negative c-plate respectively if we neglect the retardation from TAC film of polarizer.
4)If we consider the retardation from TAC film, the optimum retardation values of a- and c-plate or biaxial film are related to that of TAC film.

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III. Implement of the compensation modes in TN and VA LCDs

The compensation principle for crossed polarizers described above can be directly applied to TN and VA LCDs to enhance the contrast of display at off axis viewing angle, especially in VA mode.

The first new proposed compensation mode for TN display is shown in Fig.3. We insert one a-plate into Fuji film compensated TN display. The negative discotic Fuji film with a splayed structure offsets the most of the positive birefringence from LC and a-plate retardation film further reduces the light leakage from crossed polarizers. Fig.4 shows the simulated viewing angle characteristic of normal Fuji film compensated and Fuji film plus 80nm a-plate compensated TN display. The result shows that the off-axis contrast is dramatically enhanced in the later case. This compensation mode can be further modified into by inserting another a–plate at the front of bottom polarizer. In this case, the viewing angle as well as the chromaticity of LCD are symmetrical in left and right viewing plane.

Furthermore, we proposed to use the biaxial films to compensated VA LCDs in contrast to a- and c-plate combination used by Fujitsu Co. The configuration is shown in Fig.5. For a LC cell Δnd equal to 0.331, the optimum retarder for biaxial film $(n_x-n_y)d$ and $(n_x-n_z)d$ are around 40nm and 120nm respectively. Fig.6 shows the simulation result of the VA TN viewing angle characteristic under this compensation mode. The unprecedented good viewing angle characteristic is obtained.

The other thing worth mentioning here is the influence of retardation film on chromaticity of display in various compensation modes. It is found out that there is a huge difference on using negative a-plate instead of the positive a-plate for improvement of yellowish shift in horizontal viewing plane of display for TN as well as VA display. The detail simulation results will be published in elsewhere[7].

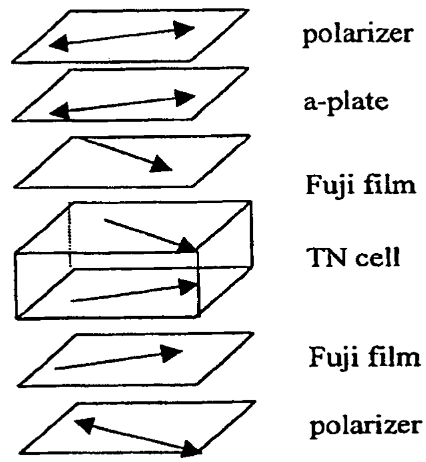

Fig.3 The a-Fuji film compensation configuration for TN display.

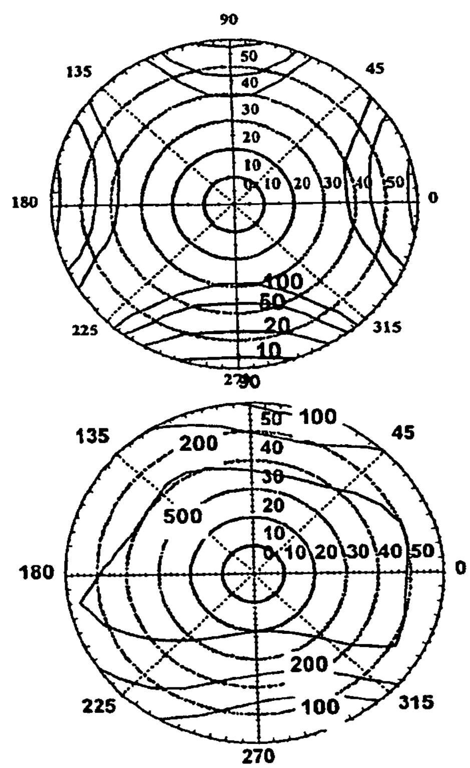

Fig.4 The viewing angle characteristic of conventional Fuji film (top) and a-Fuji (bottom) compensated TN display.

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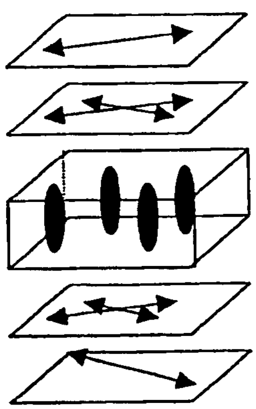

Fig.5 The new proposed compensation mode for VA LCDs.

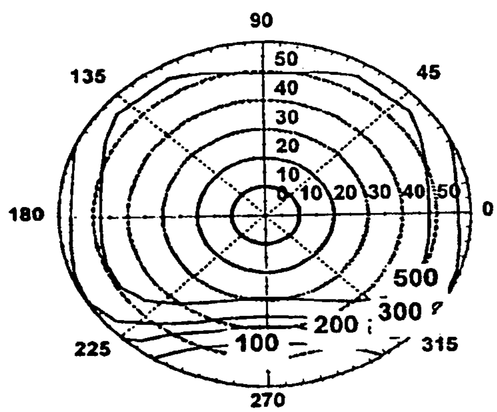

Fig.6 The viewing angle characteristic of VA TN LCDs under biaxial compensation mode. The –40nm retardation from polarizer has been taken into account.

IV. Measurement Result

We adapted biaxial film compensation mode to VA TN displays as well as EOC mode. Fig.7 shows the measured viewing angle characteristics of VA TN display under c-plates and biaxial film compensation respectively. Obviously, the display under with biaxial compensation films gives much better viewing angle characteristic.

V. Conclusion

The compensation principle to reduce the off-axis light leakage of crossed polarizers is investigated. Its implement results in new compensation modes for twist nematic (TN) and vertical aligned (VA) LCDs. After optimizing the retardation films, the simulation results show that the black state of those compensated TN and VA modes can be made wider than that of crossed polarizers. The results are also confirmed by the test cells.

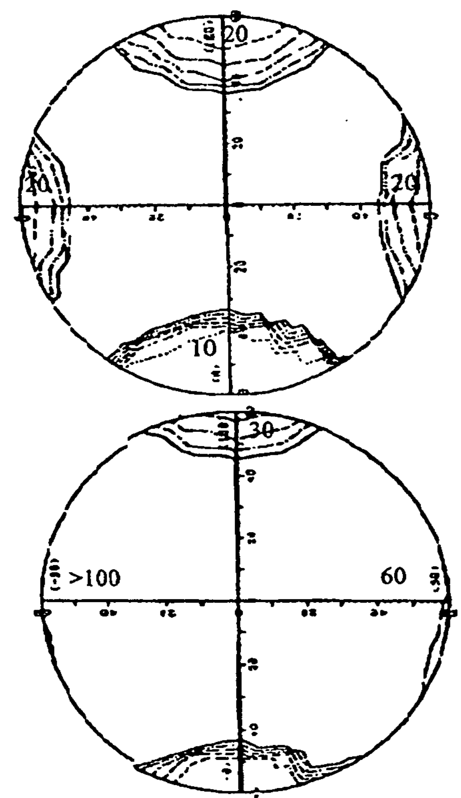

Fig.7 The viewing angle feature of VA TN display under (a) c-plate (b) biaxial film compensation.

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